DRAINAGE SYSTEM PIPE DESIGN

GEOSYNTEC CONSULTANTS

COMPUTATION COVER SHEET

Client: TVA **Project:** KIF Gypsum Disposal Facility **Project/Proposal #:** GR3731 **Task #:** 06

TITLE OF COMPUTATIONS DRAINAGE SYSTEM PIPE DESIGN

COMPUTATIONS BY:
Signature [signature]
DATE 04/12/06
Printed Name and Title: Sowmya Bulusu, Staff Engineer

ASSUMPTIONS AND PROCEDURES CHECKED BY: (Peer Reviewer)
Signature T Elkady
DATE 05/11/06
Printed Name and Title: Tamer Y. Elkady, Engineer

COMPUTATIONS CHECKED BY:
Signature Basak Gulec
DATE 05/11/06
Printed Name and Title: Basak Gulec, Engineer

COMPUTATIONS BACKCHECKED BY: (Originator)
Signature [signature]
DATE 05/10/06
Printed Name and Title: Sowmya Bulusu, Staff Engineer

APPROVED BY: (PM or Designate)
Signature R. Neil Davies
DATE May 12, 2006
Printed Name and Title: Neil Davies, Principal/Vice President

APPROVAL NOTES:

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Written by: Sowmya Bulusu Date: 06 /04 /12 (YY MM DD) Reviewed by: Basak Gulec Date: 06 /05 /03 (YY MM DD)

Client: TVA Project: Kingston Fossil Plant Gypsum Disposal Facility Project/Proposal No.: GR3731 Task No: 06

DRAINAGE SYSTEM PIPE DESIGN

PURPOSE OF ANALYSES

The purpose of this calculation package is to evaluate the performance of the drainage corridor pipes used in the proposed gypsum disposal facility located at the Kingston Fossil Plant - peninsula site (herein referred to as KIF Gypsum disposal facility). Analyses were preformed to verify that the proposed pipes have adequate structural resistance to withstand applied loads.

DESCRIPTION OF THE DRAINAGE CORRIDOR SYSTEM

The proposed drainage system for the KIF Gypsum disposal facility is a gravity flow system, which consists of six perforated high density polyethylene (HDPE) pipes (herein referenced as drainage corridor (DC) pipes), 12-in. in diameter, running along the length (northeast to southwest) of the disposal facility. The DC pipes are embedded within a gravel media that is wrapped with a geotextile filter. Plan layouts of the proposed drainage system for Phases 1 and 2 of the disposal facility are shown on Engineering Drawing 10W427-5 and 10W427-9 respectively, included as part of this permit application. Gypsum slurry will be sluiced from the dewatering facility to disposal facility and then allowed to settle. The purpose of the DC pipes is to facilitate dewatering of the gypsum in the disposal area in order to minimize the potential buildup of hydraulic head on the liner system. Water collected by the DC pipes will be conveyed to an underdrain lift station, which will in turn pump the water into the stormwater pond.

In addition to the DC pipes, a 24-in diameter decant outlet (DO) pipe is embedded in the gravel media of the central corridor. The purpose of this pipe is to convey decant water collected from Phases 1 and 2 to the underdrain lift station.

METHOD OF ANALYSIS

Pipe Structural Stability:

Calculations are performed to verify the proposed DC pipes and DO pipe are able to withstand the loads applied on it with an adequate factor of safety. Failure mechanisms that will be checked are: (i) wall crushing; (ii) wall buckling; (iii) excessive ring deflection; and (iv) excessive bending strain. Plastic pipe can be designed to resist failure by the above mechanisms using design methods presented in the technical literature [Chevron Phillips, 2003].

Stresses applied on the proposed DC and DO pipes will be estimated for two conditions: (i) the active operation condition and (ii) the post-closure condition. The active operation condition assumes that in areas where truck traffic is anticipated, 3 ft of soil/aggregate cover will be maintained on top of the pipe. The stresses due to traffic are assumed to be applied by a loaded truck with a total wheel load of 40,000 lb when full. The total stress on the pipe is then the sum of the stresses applied by the gravel layer and the stresses applied by the loaded truck, which can be calculated as described by Chevron Phillips [2003] as follows:

$$P_L = \gamma_p \cdot H + C_H \cdot \frac{I_I \cdot W_L}{L \cdot D} \qquad (1)$$

where:

P_L = stress on the pipe (psf);
γ_p = average unit weight of the overburden materials (pcf);
H = thickness of the overburden materials (ft.);
D = pipe outer diameter (ft.);
C_H = load coefficient [Chevron Phillips, 2003; Table 1], which is a function of D/(2H) and L/(2H);
W_L = wheel load (lb);
I_I = impact factor accounting for dynamic loads; and
L = effective length of pipe, which is arbitrarily defined as follows by Chevron Phillips [2003]: L = 3 ft if pipe is longer than 3 ft, and L = actual pipe length if pipe is shorter than 3-ft.

During the post-closure condition, the stress applied to the pipe is due to the overburden materials above the pipe (i.e., gravel, gypsum, and final cover soils). This stress is calculated as follows:

$$P_L = \sum \gamma_p H \qquad (2)$$

where:

P_L = stress on the collector pipe (psf);
γ_p = average unit weight of the overburden materials (pcf); and
H = thickness of the overburden materials (ft.).

Wall Crushing: Wall crushing can occur when the stress in the pipe wall, due to external vertical pressure, exceeds the compressive strength of the pipe material. The compressive stress on the pipe wall can be calculated by the following equation [Chevron Phillips, 2003]:

$$S = \frac{P_t \cdot D}{288 \cdot t} \qquad (3)$$

where:

- S = pipe wall compressive stress (psi);
- P_t = vertical load applied to the pipe (psf);
- D = pipe outside diameter (in.); and
- t = pipe wall thickness (in.).

The pipe wall compressive stress is compared to an allowable material stress value. The recommended, long-term compressive strength design value for a HDPE pipe is 800 psi as reported in the Chevron Phillips Manual [2003].

Wall Buckling: Wall buckling, a longitudinal wrinkling in the pipe wall can occur when the external vertical pressure exceeds the critical buckling pressure of the pipe/bedding aggregate system. The allowable wall buckling may be calculated using the following equation:

$$P_{WC} = \frac{5.65}{SF}\sqrt{R\ B'\ E'\frac{E}{12(SDR-1)^3}} \qquad (4)$$

where:

- P_{WC} = allowable wall buckling pressure (psf);
- SF = safety factor;
- R = buoyancy reduction factor; $R = 1 - \left(0.33\frac{H_w}{H}\right)$
- H_w = groundwater height above pipe (ft.);
- H = cover above pipe (ft.);
- B′ = elastic support factor; $B' = \frac{1}{1+4e^{-0.065H}}$
- E′ = modulus of soil reaction for pipe bedding (psf);
- E = modulus of elasticity of the pipe material (psf); and
- SDR = standard dimension ratio of the pipe.

Based on recommendation presented in Chevron Phillips [2003], a minimum factor of safety of 2 is applied. If the total vertical stress on the pipe (P_t) is less than the critical buckling pressure calculated, no buckling of pipe wall is anticipated.

Excessive Ring Deflection: Excessive ring deflection, a horizontal over-deflection of the pipe causing a reversal of curvature of the pipe wall, can occur where large external vertical pressures are applied to the pipe/bedding aggregate system. In addition, excessive ring deflection can lead to substantial loss in flow capacity. Ring deflection is calculated using the Spangler's Modified Iowa Formula [Chevron Phillips, 2003]:

$$\Delta X\% = \frac{\Delta X}{D_i}100 = \left[\frac{P_t}{144}\cdot\frac{KL}{\frac{2E}{3}\left(\frac{1}{SDR-1}\right)^3 + (0.061E')}\right].100 \qquad (5)$$

where:

- $\Delta X\%$ = ring deflection, (%);
- ΔX = horizontal deflection or change in diameter, (in);
- L = deflection lag factor (assume 1.5) [Chevron Phillips, 2003];
- K = bedding constant (assume 0.1) [Chevron Phillips, 2003];
- D_i = inside pipe diameter, (in);
- P_t = pipe crown vertical pressure, (psf);
- E = short-term modulus of elasticity of the pipe material, (psi);
- E' = modulus of soil reaction for pipe bedding material, (psi); and
- SDR = standard dimension ratio.

An allowable ring deflection of 7.5 % is assumed based on guidance from Chevron Phillips [2003].

Excessive Bending Strain: When a pipe deflects under load, bending strains are induced in the pipe wall. Bending strain occurs in the pipe wall as external pressures are applied to the pipe/bedding aggregate system. Bending strain is calculated using the following equation [Chevron Phillips, 2003]:

$$\varepsilon_b = f_d \frac{\Delta X}{D_m}\frac{2C}{D_m} \qquad (6)$$

where:

ε_b = bending strain, (%);
ΔX = vertical deflection or change in diameter, (in);
C = distance from outer fiber to wall centroid, (in);
= 0.5 * (1.06 * pipe wall thickness), [Chevron Phillips, 2003];
f_d = deformation shape factor; and
D_m = mean pipe diameter, (in);
= D – (1.06 * pipe wall thickness), [Chevron Phillips, 2003];
D = pipe outer diameter, (in).

The following are recommendations for allowable bending strain from the literature and plastic pipes manufacturers:

- An allowable bending strain of 5% is recommended by Wilson-Fahmy and Koerner [1994], based on ASSHTO guidelines.
- An allowable bending strain of 4.2% is recommended as conservative in Chevron Phillips [2003], where it is noted that strains up to 8% are reported in the literature as acceptable for a design period of 50 years.
- An allowable strain from 1 to 1.5% is recommended as conservative in Phillips 66, [1991]. This range is based on Equation 6 where $f_d = 4$. Chevron [1994] recommends an allowable bending strain between 1.5 to 2.25% for $f_d = 6$. This range incorporates a factor of safety varying with stress intensity and time duration of applied stresses.

Based on the above information and recognizing that Δy (assumed equal to the ring deflection, ΔX) is calculated very conservatively (neglecting the effect of arching), an allowable strain of 5 % is selected. A deformation factor (f_d) of 6 was also selected.

PARAMETERS USED IN ANALYSES

The characteristics of the DC and DO pipes to be used in structural stability calculations, as estimated from manufacturers' literature [Chevron Phillips, 2003], are as follows:

For DC pipes:

12-in. nominal diameter HDPE, SDR-7.3

- nominal outer diameter, D = 12.75 in.;
- minimum wall thickness, t = 1.747 in.;
- average inner diameter, D_i = 9.046 in; and
- mean diameter, D_m = 10.898 in.

For proposed DO pipe:

24-in. nominal diameter HDPE, SDR-9

- nominal outer diameter, D = 24 in.;
- minimum wall thickness, t = 2.667 in.;
- average inner diameter, D_i = 18.346 in; and
- mean diameter, D_m = 21.173 in.

Pipe Perforation Sizing:

For proposed DC pipe:

- d_{85} = particle size of the pipe bedding material for which 85 percent by weight of the particles are finer; assuming #57 gravel, d_{85} =16 to 22 mm as shown in Figure 1. Conservatively assume d_{85} = 16 mm (0.630 in.); and
- F = factor varying from 1.2 to 2 (assume 1.2).

Structural Stability:

- Unit weight of overburden materials
  - bedding (gravel) layer = 120 pcf;
  - final cover system = 120 pcf; and
  - waste (gypsum) = 100 pcf.

Information on the unit weight of gypsum in these analyses is obtained from MACTEC [2004], and MACTEC [1995]. The overburden material on the pipe will consist of dry stack gypsum and fine gypsum. Dry stack gypsum, which will be dewatered at the plant before it is transported to the disposal facility, will be placed above an elevation of approximately 900 feet. The unit weight of dry stack gypsum is approximately 107 pcf as indicated in MACTEC [1995]. Fine grained gypsum is a by-product of the rim-ditch method of sluiced material placement. The unit weight of 100 pcf is reported for fine grained gypsum [MACTEC, 2004]. Since a majority of the gypsum on the pipes (upto an elevation of approximately 900 ft) will be fine grained gypsum, a unit weight of 100 pcf is used in the analyses for overburden gypsum.

- Stresses on DC and DO pipes

<u>active-operation condition:</u>

- H = 3.0 ft;

- W_L = wheel load = 40,000 lb (assumed based on a standard loaded truck) [Chevron Phillips, 2003];
- I_I = impact factor accounting for dynamic loads = 2.5 [Chevron Phillips, 2003];
- L = effective length of pipe = 3 ft;
- C_H = load coefficient (Table 1) = 0.140 *(for proposed DC pipe)*, = 0.242 *(for proposed DO pipe)*; and
- D = outer pipe diameter
  = 1.061 ft = 12.75 in. *(for proposed DC pipe)*,
  = 2.0 ft = 24.0 in. *(for proposed DO pipe)*.

post-closure condition:

- bedding layer (gravel) = 3.0 ft
- final cover system = 3.0 ft;
- waste = 218 ft (thickness of waste only, excluding final cover and gravel thicknesses, i.e., 221–3 = 218 ft., see Figures 2 and 3); and
- σ_{max} = 3.0 * 120 + 218 * 100 + 3.0 * 120
  = 22, 520 psf = 156.39 psi

Wall Crushing:

- P_t = vertical pressure applied to the pipe (psi);
- σ_y = allowable pipe wall compressive stress = 115200 psf = 800 psi [Chevron Phillips, 2003];

Wall Buckling:

- SF = safety factor = 2;
- H_w = groundwater height above pipe = 0 ft;
  (Due to the relative high permeability of the gravel layer, it is anticipated that the central drainage corridor will facilitate drainage of water during facility operations and therefore reduce head on top of the pipe. Therefore, for the purpose of the analysis presented herein, the height of water above the pipe (H_w) is assumed to be zero.)

- H = cover above pipe = 224 ft (height of gypsum + final cover + gravel; see Figures 2 and 3);
- E' = modulus of soil reaction for pipe bedding = 4.32 x10^5 psf (3,000 psi) (Table 2);
- E = modulus of elasticity of the pipe material (Table 3) = 4.06 x 10^6 psf (28,200 psi) *(for 50 years @ 73° F)*; and
- SDR = 7.3 *(for proposed DC pipe),*
  = 9.0 *(for proposed DO pipe).*

Excessive Ring Deflection:

- L = deflection lag factor (assume 1.5) [Chevron Phillips, 2003];
- K = bedding constant (assume 0.1) [Chevron Phillips, 2003];
- D_i = inside pipe diameter = 9.046 in. *(for proposed DC pipe),*
  = 18.346 in. *(for proposed DO pipe)*;
- E = short-term modulus of elasticity of pipe material *(@ 73° F)*
  = 1.58 x 10^7 psf = 110,000 psi, [Chevron Phillips, 2003];
- E' = modulus of soil reaction for pipe bedding material = 3,000 psi, [Chevron Phillips, 2003];

Excessive Bending Strain:

- C = distance from outer fiber to wall centroid
  = 0.5 * (1.06* pipe wall thickness);
- f_d = deformation shape factor = 6; and
- D_m = mean diameter
  = pipe outer diameter D – (1.06 * pipe wall thickness)
  = 10.898 in. *(for proposed DC pipe),*
  = 21.173 in. *(for proposed DO pipe).*

CALCULATIONS

See following pages for calculations.

CALCULATIONS FOR STRUCTURAL PERFORMANCE (PROPOSED DC PIPE)

Written by: Sowmya Bulusu Date: 06 /04 /12 (YY MM DD) Reviewed by: Basak Gulec Date: 06 /05 /03 (YY MM DD)

Client: TVA Project: Kingston Fossil Plant Gypsum Disposal Facility Project/Proposal No.: GR3731 Task No: 06

PROPOSED DC PIPE DESIGN

Pipe Type:

Name: 12-in nominal diameter HDPE Pipe

Norminal Outer Diameter	D =	12.75	in
Minimum wall thickness	t =	1.747	in
Average inner diameter	D_i =	9.046	in
Standard Dimension Ratio of pipe	SDR =	7.3	

Pipe Perforation Sizing

Material : assuming #57 gravel, d85 =16~22mm

d_{85} = 16 mm

Factor varying from 1.2 ~ 2.0 F = 1.2

$d_{hmax} = d_{85} / F$

= 16 / 1.2

= 13.3 mm

= 0.52 inch Use 0.50 inch

Stress on collector pipe

Active Operation Condition

Wheel Load	W_L =	40000	lbs	From Chevron Phillips, 2003
Impact Factor	I_f =	2.5		From Chevron Phillips, 2003
Length of pipe	L =	3.0	ft	Note: L = 3-ft if pipe > 3-ft, L = actual length If pipe < 3-ft
Unit weight of overburden soil	γ_p =	120	pcf	
Thickness of overburden soil	H =	3	ft	L / (2*H) = 0.50 D/ (2*H) = 0.18
Load coefficient	C_H =	0.140		[Chevron Phillips, 2003], Table 1

$$P_L = \gamma_p \cdot H + C_H \cdot \frac{I_f \cdot W_L}{L \cdot D}$$

= 4752 psf

Post Closure Condition

Post Closure Condition

Layer No.	γ_p (pcf)	H (ft)	γ_p x H (psf)
1 (Final Cover)	120	3.0	360
2 (Waste)	100	218.0	21800
3 (Liner System)	120	3.0	360
4			
5			
6			

Total = 22520 psf = 156.39 psi

Maximum Vertical Stress = P_t = 22520 psf = 156.39 psi

Wall Crushing

Allowable Compressive Stress	σ_y = 115200 psf =	800	psi	From Chevron Phillips, 2003

Actual Wall compressive stress $$S = \frac{P_t \cdot D}{288 \cdot t}$$ From Chevron Phillips, 2003

= **570.68** psi ≤ 800 psi <= OK

Wall Buckling

Height of water table above Pipe	H_w = 0 ft			
Height of Waste+Final Cover above Pipe	H = 224 ft			From Chevron Phillips, 2003
modulus of elasticity of pipe	E = 4060800.0 psf =	28200	psi	For 50 years @ 73°F
modulus of soil reaction	E' = 432000.0 psf =	3000	psi	From Chevron Phillips, 2003

$$P_{WC} = \frac{5.65}{SF} \cdot \sqrt{R \cdot B' \cdot E' \cdot \frac{E}{12 \cdot (SDR - 1)^3}}$$ From Chevron Phillips, 2003

where

$$R = 1 - \left(0.33 \cdot \frac{H_w}{H}\right)$$ and $$B' = \frac{1}{1 + 4 \cdot e^{-0.065 \cdot H}}$$ From Chevron Phillips, 2003

Water Buoyancy Factor	R = 1.0000
Coefficient of Elastic Support	B' = 1.0000
Factor of Safety	SF 2

Allowable Critical Buckling Pressure P_{WC} = **68307** psf

$P_t < P_{WC}$? **Yes** <= OK

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MAXIMUM RING DEFLECTION AND RING BENDING STRAIN

Ring Deflection Using the Modified Spangler Equation:

$$\frac{\Delta X}{D_i} = \frac{P_t}{144} \cdot \frac{K \cdot L}{\left(\frac{2 \cdot E}{3} \frac{1}{(SDR-1)^3}\right) + (0.061 \cdot E')}$$

L	1.5	
K	0.1	
P_t	22520.00	psf
D_i	9.046	in.
E	110000	psi
E'	3000	psi
SDR	7.3	

ΔX = maximum horizontal deflection or change in diameter, in;
L = deflection lag factor (assume 1.5) [Chevron Phillips, 2003];
K = bedding constant (assume 0.1) [Chevron Phillips, 2003];
P_t = pipe Crown Vertical Pressure, psf;
E = short-term modulus of elasticity of the pipe material @ 73° F, [Chevron Phillips, 2003], psi;
E' = the modulus of soil reaction for pipe bedding material [Chevron Phillips, 2003], psi;
SDR = standard dimension ratio [Chevron Phillips, 2003]
ΔX% = ring deflection, %, = 100 ($\Delta X/D_i$).
Di = inside pipe diameter, in.

Change in diameter, ΔX = 0.45 in.

$$\Delta X\,\% = \frac{\Delta X}{D_i}.100$$

= 4.93 % <= Ring Deflection < 7.5%, OK

Ring Bending Strain

$$\varepsilon_b = f_d \cdot \frac{\Delta X}{D_m} \cdot \frac{2 \cdot C}{D_m}$$

D_m	10.898	
f_d	6	
C	0.926	in

ε_b = bending strain, %;
ΔX = maximum vertical deflection or change in diameter, in;
Dm = mean pipe diameter, in, = D - (1.06* pipe wall thickness); [Chevron Phillips, 2003]
f_d = deformation shape factor
C = distance from outer fiber to wall centroid, in. = 0.5 * (1.06* pipe wall thickness); [Chevron Phillips, 2003].

Bending strain, ε_b = 4.17 % <= Bending Strain < 5.0%, OK

CALCULATIONS FOR STRUCTURAL PERFORMANCE (PROPOSED DO PIPE)

Written by: Sowmya Bulusu Date: 06 /04 /12 (YY MM DD) Reviewed by: Basak Gulec Date: 06 /05 /03 (YY MM DD)

ent: TVA Project: Kingston Fossil Plant Gypsum Disposal Facility Project/Proposal No.: GR3731 Task No: 06

PROPOSED DO PIPE DESIGN

Pipe Type:

Name: 12-in nominal diameter HDPE Pipe

Norminal Outer Diameter	$D =$	24	in
Minimum wall thickness	$t =$	2.667	in
Average inner diameter	$D_i =$	18.346	in
Standard Dimension Ratio of pipe	$SDR =$	9	

Stress on collector pipe

Active Operation Condition

Wheel Load	$W_L =$	40000	lbs	From Chevron Phillips, 2003
Impact Factor	$I_I =$	2.5		From Chevron Phillips, 2003
Length of pipe	$L =$	3.0	ft	Note: L = 3-ft if pipe > 3-ft, L = actual length If pipe < 3-ft
Unit weight of overburden soil	$\gamma_p =$	120	pcf	
Thickness of overburden soil	$H =$	3	ft	L / (2*H) = 0.50 D/ (2*H) = 0.33
Load coefficient	$C_H =$	0.242		[Chevron Phillips, 2003], Table 1

$$P_L = \gamma_p \cdot H + C_H \cdot \frac{I_I \cdot W_L}{L \cdot D}$$

= 4393 psf

Post Closure Condition

Post Closure Condition

Layer No.	γ_p (pcf)	H (ft)	$\gamma_p \times H$ (psf)
1 (Final Cover)	120	3.0	360
2 (Waste)	100	218.0	21800
3 (Liner System)	120	3.0	360
4			
5			
6			

Total = 22520 psf = 156.39 psi

Maximum Vertical Stress = $P_t =$ 22520 psf = 156.39 psi

Written by:	Sowmya Bulusu	Date:	06 /04 /12 (YY MM DD)	Reviewed by:	Basak Gulec	Date:	06 /05 /03 (YY MM DD)

Client: TVA Project: Kingston Fossil Plant Gypsum Disposal Facility Project/Proposal No.: GR3731 Task No: 06

Wall Crushing

Allowable Compressive Stress	σ_y = 115200 psf =	800	psi		From Chevron Phillips, 2003

Actual Wall compressive stress

$$S = \frac{P_t \cdot D}{288 \cdot t}$$

From Chevron Phillips, 2003

= **703.66** psi ≤ 800 psi <= OK

703.6620422

Wall Buckling

Height of water table above Pipe	H_w = 0 ft			
Height of Waste+Final Cover above Pipe	H = 224 ft			From Chevron Phillips, 2003
modulus of elasticity of pipe	E = 4060800.0 psf =	28200	psi	For 50 years @ 73°F
modulus of soil reaction	E' = 432000.0 psf =	3000	psi	From Chevron Phillips, 2003

$$P_{WC} = \frac{5.65}{SF} \cdot \sqrt{R \cdot B' \cdot E' \cdot \frac{E}{12 \cdot (SDR - 1)^3}}$$

From Chevron Phillips, 2003

where

$$R = 1 - \left(0.33 \cdot \frac{H_w}{H}\right) \quad \text{and} \quad B' = \frac{1}{1 + 4 \cdot e^{-0.065 \cdot H}}$$

From Chevron Phillips, 2003

Water Buoyancy Factor	R =	1.0000
Coefficient of Elastic Support	B' =	1.0000
Factor of Safety	SF	2

Allowable Critical Buckling Pressure P_{WC} = 47735 psf

$P_t < P_{WC}$? Yes <= OK

MAXIMUM RING DEFLECTION AND RING BENDING STRAIN

Ring Deflection Using the Modified Spangler Equation:

$$\frac{\Delta X}{D_i} = \frac{P_t}{144} \cdot \frac{K \cdot L}{\left(\frac{2 \cdot E}{3} \frac{1}{(SDR-1)^3}\right) + (0.061 \cdot E')}$$

L	1.5	
K	0.1	
P_t	22520.00	psf
D_i	18.346	in.
E	110000	psi
E'	3000	psi
SDR	9	

ΔX = maximum horizontal deflection or change in diameter, in;
L = deflection lag factor (assume 1.5) [Chevron Phillips, 2003];
K = bedding constant (assume 0.1) [Chevron Phillips, 2003];
P_t = pipe Crown Vertical Pressure, psf;
E = short-term modulus of elasticity of the pipe material @ 73° F, [Chevron Phillips, 2003], psi;
E' = the modulus of soil reaction for pipe bedding material [Chevron Phillips, 2003], psi;
SDR = standard dimension ratio [Chevron Phillips, 2003]
ΔX% = ring deflection, %, = 100 ($\Delta X/D_i$).
Di = inside pipe diameter, in.

Change in diameter, ΔX = 1.32 in.

$$\Delta X\,\% = \frac{\Delta X}{D_i} . 100$$

= 7.19 % <= Ring Deflection < 7.5%, OK

Ring Bending Strain

$$\varepsilon_b = f_d \cdot \frac{\Delta X}{D_m} \cdot \frac{2 \cdot C}{D_m}$$

D_m	21.173	
f_d	6	
C	1.414	in

ε_b = bending strain, %;
ΔX = maximum vertical deflection or change in diameter, in ;
Dm = mean pipe diameter, in, = D - (1.06* pipe wall thickness); [Chevron Phillips, 2003]
f_d = deformation shape factor
C = distance from outer fiber to wall centroid, in. = 0.5 * (1.06* pipe wall thickness); [Chevron Phillips, 2003].

Bending strain, ε_b = 4.99 % <= Bending Strain < 5.0%, OK

SUMMARY AND CONCLUSIONS

Assumptions:

Proposed DC pipes:

- 12-inch HDPE SDR-7.3 perforated pipe

Proposed DO pipes:

- 24-inch HDPE SDR-9.0 solid pipe

Installation of proposed pipes:

- Pipe bedding consists of # 57 stone (crushed)
- Minimum 2.5-ft of drainage gravel and cover soil placed before construction vehicles are permitted to pass over the pipes.

Analysis summary and conclusions:

Structural Stability:

For proposed DC pipe

- **Wall crushing**
  Pipe wall compressive stress = 570.68 psi < Allowable compressive stress (800 psi) → OK
- **Wall buckling**
  Allowable critical buckling pressure = 68,307 psf > Total vertical stress on pipe (22,520 psf) → OK
- **Ring deflection** = 4.93 % < allowable ring deflection (7.5 %) → OK
- **Bending strain** = 4.17 % < allowable strain (5%) → OK

For proposed DO pipe

- **Wall crushing**
  Pipe wall compressive stress = 703.66 psi < Allowable compressive stress (800 psi) → OK
- **Wall buckling**
  Allowable critical buckling pressure = 47,735 psf > Total vertical stress on pipe (22,520 psf) → OK
- **Ring deflection** = 7.19 % < allowable ring deflection (7.5 %) → OK

- **Bending strain** = 4.99 % < allowable strain (5%) → OK

Based on the above results, the specified pipes are anticipated to perform satisfactorily under the active and post-closure conditions for the KIF Gypsum Disposal Facility.

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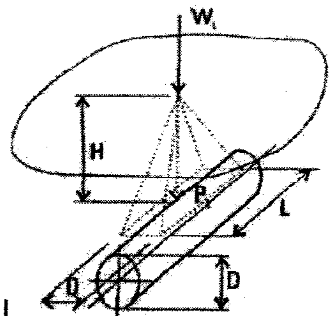
Written by: Sowmya Bulusu Date: 06 /04 /12 (YY MM DD) Reviewed by: Basak Gulec Date: 06 /05 /03 (YY MM DD)

Client: TVA Project: Kingston Fossil Plant Gypsum Disposal Facility Project/Proposal No.: GR3731 Task No: 06

Table 1. Load Coefficient, C_H [Chevron Phillips, 2003]



D/2H	L/2H 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5	2.0	20.0
0.1	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.127
0.18					0.14									
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.346	0.355	0.361
0.33					0.242									
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.442	0.454	0.462
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.550
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.625
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.574	0.597	0.628	0.655	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.743	0.766	0.783
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.775	0.800	0.818
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.821	0.849	0.871
1.5	0.121	0.238	0.346	0.422	0.525	0.596	0.655	0.703	0.743	0.775	0.821	0.863	0.895	0.920
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.895	0.930	0.960
20.0	0.127	0.248	0.361	0.462	0.550	0.625	0.688	0.740	0.783	0.818	0.871	0.920	0.960	1.000

Table 2. Bureau of Reclamation Average Values of E' for Iowa Formula (Initial Deflection [Chevron Phillips, 2003]

Soil type – pipe bedding material (Unified Classification)†	*E' for Degree of Bedding Compaction, lb/in²*			
	Dumped	*Slight (<85% Proctor <40% relative density)*	*Moderate (48%-95% Proctor 40%-70% relative density)*	*High (>95% Proctor >70% relative density)*
Fine-grained soils (LL>50)‡ Soils with medium to high plasticity CH, MH, CH-MH	No data available; consult a competent soils engineer; otherwise, use E' = 0.			
Fine-grained soils (LL<50) Soils with medium to no plasticity CL, ML, CL-ML, with <25% coarse grained particles	50	200	400	1000
Fine-grained soils (LL<50) Soils with medium to no plasticity CL, ML, CL-ML, with >25% coarse grained particles Coarse-grained soils with fines GM, GC, SM, SC◊ contains >12% fines	100	400	1000	2000
Coarse-grained soils with little or no fines GW, GP, SW, SP◊ contains <12% fines	200	1000	2000	3000
Crushed rock	1000	3000	3000	3000
Accuracy in terms of percentage deflection▼	±2%	±2%	±1%	±0.5%

† ASTM D 2487; USBR Designation E-3. ‡ LL = Liquid limit. ◊ Or any borderline soil beginning with one of these symbols, i.e., GM-GC, GC-SC. ▼For ±1% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%.

Note – Values applicable only for fills less than 50 ft (15 m). No safety factor included in table values. For use in predicting initial deflections only; appropriate Deflection Lag Factor must be applied for long-term deflections. If bedding falls on the borderline between two compaction categories, select the lower E' value or average the two values. Percentage Proctor based on laboratory maximum dry density from test standards using 12,500 ft-lb/ft³ (598,000 J/m²) (ASTM D 698, AASHTO T-99, USBR Designation E-11). 1 lb/in² = 6.895 kPa.

Table 3. Typical Elastic Modulus for DriscoPlex® [Chevron Phillips, 2003]

Load Duration	*Elastic Modulus†, 1000 psi (MPa), at Temperature, °F (°C)*							
	-20 (-29)	*0 (-18)*	*40 (4)*	*60 (16)*	*73 (23)*	*100 (38)*	*120 (49)*	*140 (60)*
Short-Term	300.0 (2069)	260.0 (1793)	170.0 (1172)	130.0 (896)	110.0 (758)	100.0 (690)	65.0 (448)	50.0 (345)
10 h	140.8 (971)	122.0 (841)	79.8 (550)	61.0 (421)	57.5 (396)	46.9 (323)	30.5 (210)	23.5 (162)
100 h	125.4 (865)	108.7 (749)	71.0 (490)	54.3 (374)	51.2 (353)	41.8 (288)	27.2 (188)	20.9 (144)
1000 h	107.0 (738)	92.8 (640)	60.7 (419)	46.4 (320)	43.7 (301)	35.7 (246)	23.2 (160)	17.8 (123)
1 y	93.0 (641)	80.6 (556)	52.7 (363)	40.3 (278)	38.0 (262)	31.0 (214)	20.2 (139)	15.5 (107)
10 y	77.4 (534)	67.1 (463)	43.9 (303)	33.5 (231)	31.6 (218)	25.8 (178)	16.8 (116)	12.9 (89)
50 y	69.1 (476)	59.9 (413)	39.1 (270)	29.9 (206)	28.2 (194)	23.0 (159)	15.0 (103)	11.5 (79)

† Typical values based on ASTM D 638 testing of molded plaque material specimens.

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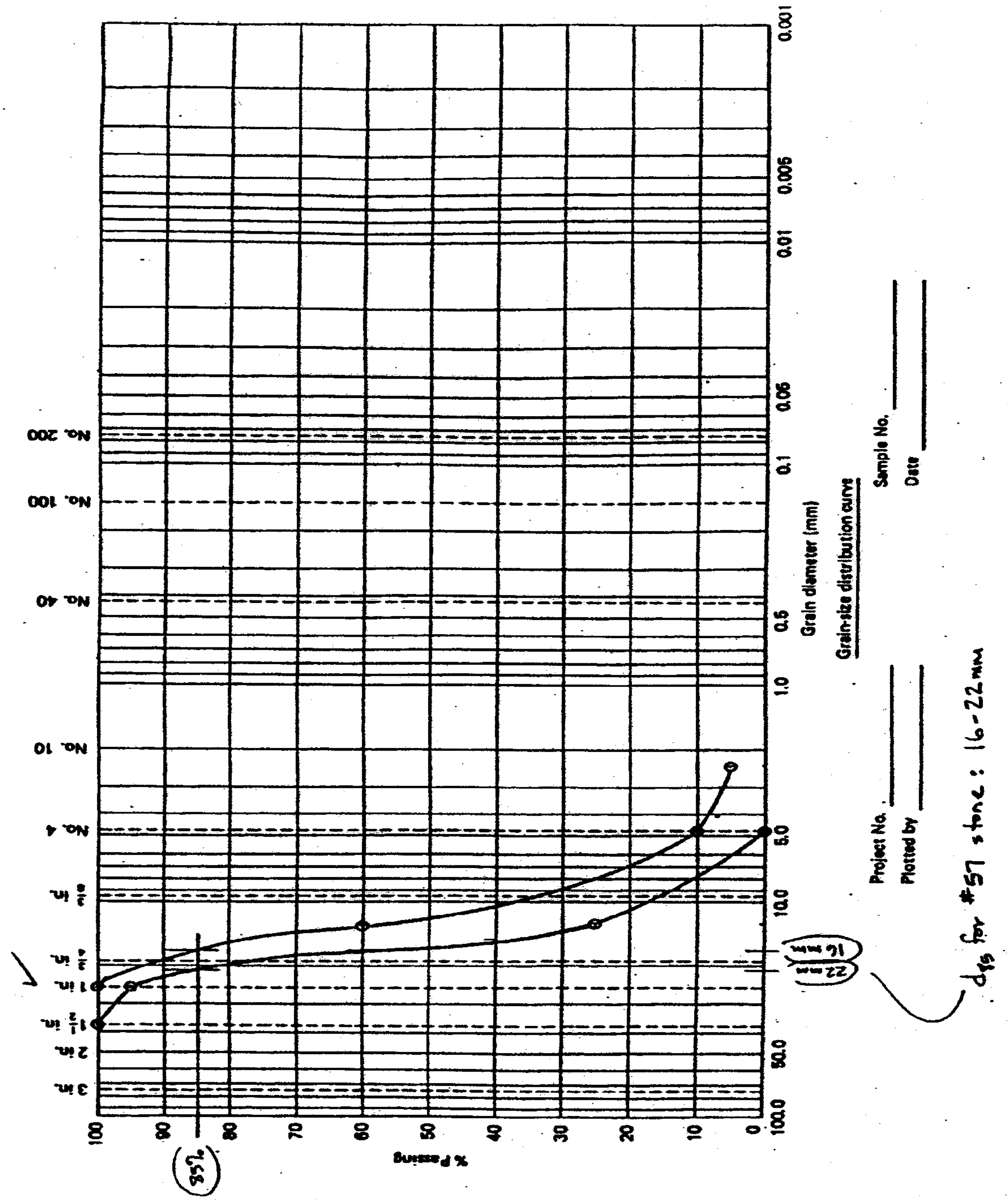

Figure 1. Grain Size Distribution Curve for # 57 Stone