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Technical Memorandum

To:	Joel Carrasco	**From:**	Mike Thornbrue
Company:	Tetra Tech	**Date:**	August 13, 2010
Re:	Rosemont Heap Leach Pad Drain Pipe Deflection	**Doc #:**	214/10-320877-5.3
CC:	David R. Krizek, P.E. (Tetra Tech); and Troy Meyer, P.E. (Tetra Tech)		

1.0 Introduction

This Technical Memorandum documents the estimated deflection of the solution collection pipes 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. 3b on page 6 of 18.

- *Item 3b – Leachate Collection Pipes Network: Pipe loading at the ultimate design height of the heap does not threaten the structural integrity of the pipe. The collector and header pipes network can provide sufficient capacity for transporting leachate over the operation life of the facility; withstand the stresses caused by the maximum loading height of the ore heap without significant deformation or buckling and with adequate factor of safety. This demonstration should be based on manufacturer's technical data on product specifications or case studies for the pipes (ADS-N-12 Corrugated High Density Polyethylene pipe) used under similar application.*

The results of our calculations indicate that the collection pipes will provide sufficient capacity without significant deformation caused by the maximum loading of the heap.

2.0 Drain Pipe Design

As documented in the technical memorandum titled, "Rosemont Heap Leach Drain Pipe Design" (Tetra Tech, 2009), the Heap Leach Facility has been designed to meet or exceed the recommendations for Best Available Demonstrated Control Technology (BADCT) as established by the Arizona Department of Environmental Quality (ADEQ) (2004).

The drain pipe network will consist of corrugated, dual wall, perforated N-12 high-density, polyethylene (HDPE) pipes buried in three (3) feet of permeable (about $1x10^{-2}$ cm/sec) Overliner Drain Fill (ODF) material. The drain pipes will be arranged in a herringbone pattern that will convey Pregnant Leach Solution (PLS) and stormwater to the PLS Pond located at the base of

the Heap Leach Pad. The four (4) inch diameter pipes will connect to a series of ten (10) inch diameter primary pipes, 15-inch diameter collector pipes, and 18-inch diameter header pipes.

The pipe network has been designed to convey 150% of the anticipated PLS flows plus the stormwater from the 100-year, 24-hour storm event to the PLS Pond under gravity flow conditions.

3.0 Plastic Piping Design Guidance

Prescriptive BADCT design guidance recommends that the drainage gravel and solution collection piping provide for the removal of solution from the base of the leach ore pile such that the average and maximum hydraulic head over the liner are less than two (2) feet and five (5) feet, respectively.

The Association of State Highway and Transportation Officials (AASHTO) recommends a maximum allowable long-term strain (deflection) of five (5) percent for buried, corrugated polyethylene pipes (AASHTO, 2007). However, this standard is intended for roadway design and is impractical as guidance for heap leach pad design.

In a paper published in 2005, John F. Lupo, P.E. noted that non-pressurized HDPE pipes may have severe deformation and buckling if the vertical deflections in the pipe exceed 20%. Therefore, Mr. Lupo recommends allowing a maximum vertical deflection of 15% if the pipes are sized to accommodate a reduction in flow capacity due to deflection (Lupo, 2005).

In 2007, Knight Piésold conducted a large-scale laboratory vertical load test on segment of 24-inch (600-mm) diameter Corrugated Plastic Tubing (CPT) pipe manufactured by Advanced Drainage Systems Incorporated (ADS). The testing was conducted at the U.S. Bureau of Reclamation (USBR) in Denver, CO using a full scale cross-section of a heap leach pad liner system including soil liner, geomembrane, protective soil, a drain pipe, and a drainage layer. The testing was conducted to evaluate the performance of the pipe under the loading conditions expected on a heap leach pad stacked to a height of 170 meters (558 feet). The testing indicated a deformation of 5.1 inches, approximately 21%, at 140 meters (459 feet) and a vertical deformation of 7.02 inches, approximately 29%, at 170 meters (558 feet). The deformations were considered acceptable because the design of the leach pad piping system allowed for a 50% reduction in flow capacity due to pipe deformations.

4.0 Pipe Deformation Calculations

Tetra Tech performed deflection calculations for each pipe size that will be used on the proposed Heap Leach Pad. The calculations provided in Attachment 1 are based on the work of Burns and Richard (1964).

The calculations are based on the following information for each pipe size (ADS, 2009):

- Outside Diameter of the Pipe;
- Wall Thickness at the Valley of the Corrugation;
- Unit Area of the Wall;
- Unit Moment of Inertia; and
- The Distance from the Inner Wall to the Neutral Axis of the Pipe.

The calculations are also based on the following information (AASHTO, 2007):

- The Flexural Modulus of 110,000 pounds per square inch (psi).

The following values were estimated based on engineering judgment and experience:

- The Modulus of Soil Reaction at 5' of cover for the ODF was estimated at 1,000 psi. The Modulus of Soil Reaction can range from 470 psi to over 1,000 psi based on the geostatic load of the material above the ODF;
- Poisson's Ration was estimated to be 0.25. Typical values for this application range from 0.25 to 0.30. A value of 0.25 provides the most conservative calculation (Coduto, 2001);
- The Unit Weight of the soil (leach pad) was estimated to be 125 pounds per cubic foot (pcf); and
- The maximum possible height of the stacked ore of 450 feet was selected for the height of fill above the crown of the pipe.

5.0 Conclusions

In general, if the leach ore is stacked to a height of 450 feet, each pipe is likely to experience an 18% vertical deformation as shown in Attachment 1. The pipe deflection results in a loss of 10% of the cross sectional area of the pipes. As previously stated, the drain pipe system has been designed to accommodate 150% of the PLS design flows plus the flows from a 100-year, 24-hour storm event. Therefore, the deflection is acceptable.

REFERENCES

Advanced Drainage Systems, Incorporated (ADS) (2009). *ADS, Inc. Drainage Handbook.* Dated August 2009.

American Association of State Highway and Transportation Officials (AASHTO) (2007). *AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications, Customary U.S. Units, 4th Edition.* Section 12 Buried Structures and Tunnel Liners. Dated 2007.

Arizona Department of Environmental Quality (ADEQ) (2004). Arizona Mining Best Available Demonstrated Control Technology (BADCT) Guidance Manual Aquifer Protection Program, Publication TB-04-01.

Burns, J.Q. and Richard, R.M., (1964). *Attenuation of Stresses for Buried Conduits:, Proc. Symp. Soil-Structure Interaction*, University of Arizona.

Coduto, D. P. (2001). *Foundation Design Principles and Practices Second Edition.* Published by Prentice Hall. Upper Saddle River, New Jersey 07458. pp 502.

Knight Piésold and Co, (2007). *Advanced Drainage Systems CPT Pipe Evaluation Load Test Report.* Prepared for Advanced Drainage Systems. Report Dated August 16, 2007.

Lupo, J. F. Golder Associates Inc. (2005). *Heap Leach Facility Liner Design*. Dated November 2005.

Tetra Tech, Carrasco, J. (2009). *Rosemont Heap Leach Drain Pipe Design*. Technical Memorandum to File. Technical Memorandum dated May 4, 2009.

ATTACHMENT 1
TABLES

Pipe Crushing Calculations
4" ADS N-12

PIPE PARAMETERS - AASHTO M294, Type S

Effective Radius (in), R = 2.50
Outside Diameter (in), D = 4.8
Thickness (in), t = 0.03
Unit Area of Wall (in²/in), A = 0.063
Unit Moment of Inertia (in⁴/in), I = 0.0014
Flexural Modulus (psi), E_f = 110,000
Ring Compression Modulus (psi), E_{rc} = 110,000
Flexural Stiffness (psi), $K_f = 6E_fI/R^3$ = 59
Ring Compression Stiffness (psi), $K_{rc} = E_{rc}A/R$ = 2,778
Distance From Inner Wall to N.A. (in), c* = 0.12

SOIL PARAMETERS - Good Granular Soil

Modulus of Soil Reaction at 5' of Cover (psi), E'_5 = 1000
Modulus of Soil Reaction (psi), E' = 4161
Poisson's Ratio, u = 0.25
Constr Mod (psi), M*=E*(1-u)/((1+u)(1-2u))= 4992.8
Lateral Stress Ratio = K = u/(1-u) = 0.333
Sym Lateral Stress Ratio = B = (1/2)(1+K) =0.667
Antisym Lat Stress Ratio = C = (1/2)(1-K) =0.333

SOIL/STRUCTURE PARAMETERS (full slippage)

Ring Flexibility Ratio, UF =(1+K)M*/K_c = 2.40
Bending Flexibility Ratio, VF = (1-K)M*/K_f= 55.9

STRESS FUNCTION COEFFICIENTS

Constant Term, a_0* = 0.318
cos(2*theta), a_2** = 0.974
sin(2*theta), b_2** = 0.961

LOAD PARAMETERS

Unit Weight of Soil (lb/ft³) = 125
Height of Fill Above Crown (ft) = 450.0
Surcharge Pressure (psi), P = 390.6

RESPONSE OF PIPE WALL

deg c.c.w. from horiz	radial soil press P_r(psi)	radial defl w(in)	tang defl v(in)	circum wall thrust N(#/in)	wall bend mom(M) (#-lb/in)	ring comp stress (psi)	inner bend stress (psi)	outer bend stress (psi)	total stress inner (psi)	total stress outer (psi)
0	167.5	-0.124	0.000	452	25	-7171	-2145	-1698	-9316	-8869
10	168.1	-0.107	0.049	451	24	-7163	-2036	-1612	-9199	-8775
20	169.9	-0.058	0.092	450	20	-7140	-1722	-1363	-8862	-8503
30	172.6	0.018	0.124	448	14	-7104	-1242	-983	-8346	-8087
40	175.9	0.110	0.141	445	8	-7060	-652	-516	-7712	-7577
50	179.5	0.209	0.141	442	0	-7014	-25	-20	-7039	-7033
60	182.8	0.302	0.124	439	-7	-6970	565	447	-6405	-6523
70	185.5	0.377	0.092	437	-12	-6934	1045	827	-5889	-6107
80	187.2	0.426	0.049	435	-16	-6911	1359	1076	-5552	-5835
90	187.8	0.444	0.000	435	-17	-6903	1468	1162	-5435	-5741
100	187.2	0.426	-0.049	435	-16	-6911	1359	1076	-5552	-5835
110	185.5	0.377	-0.092	437	-12	-6934	1045	827	-5889	-6107
120	182.8	0.302	-0.124	439	-7	-6970	565	447	-6405	-6523
130	179.5	0.209	-0.141	442	0	-7014	-25	-20	-7039	-7033
140	175.9	0.110	-0.141	445	8	-7060	-652	-516	-7712	-7577
150	172.6	0.018	-0.124	448	14	-7104	-1242	-983	-8346	-8087
160	169.9	-0.058	-0.092	450	20	-7140	-1722	-1363	-8862	-8503
170	168.1	-0.107	-0.049	451	24	-7163	-2036	-1612	-9199	-8775
180	167.5	-0.124	0.000	452	25	-7171	-2145	-1698	-9316	-8869

CALCULATION OF RING SHORTENING

deg c.c.w. from horiz	ring comp stress (psi)	ring comp strain (in/in)	ring shortening (in)
0	-7171	-0.065191	-0.0284
10	-7163	-0.0651	-0.0284
20	-7140	-0.064906	-0.0283
30	-7104	-0.064582	-0.0281
40	-7060	-0.064184	-0.0279
50	-7014	-0.063761	-0.0278
60	-6970	-0.063363	-0.0276
70	-6934	-0.063039	-0.0275
80	-6911	-0.062828	-0.0274
90	-6903	-0.062754	-0.0273
100	-6911	-0.062828	-0.0274
110	-6934	-0.063039	-0.0275
120	-6970	-0.063363	-0.0276
130	-7014	-0.063761	-0.0278
140	-7060	-0.064184	-0.0279
150	-7104	-0.064582	-0.0281
160	-7140	-0.064906	-0.0283
170	-7163	-0.0651	-0.0284
180	-7171	-0.065191	-0.0284
		SUM (I/2 circle) =	-0.5298

COMMENTS

1. *This is 4" diameter ADS N-12*
2. *Flexural and compressive modulus are taken as 110,000 psi.*
3. *Typical E'_5 values (in psi) for various soils are listed in the table below:*

Type of Soil	Standard AASHTO Relative Compaction 85%	90%	95%
Fine-grained soils with less than 25% sand (CL, ML, DL-ML)	500	700	1000
Coarse-grained soils with fines (SM, SC)	600	1000	1200
Coarse-grained soils with little or no fines (SP, SW, GP, GW)	700	1000	1600

Vertical deflection (%) = 17.78
Horizontal deflection (%) = -9.96
Critical Buckling Pressure (psi), P_{cr}= 187.6
Radial Soil Pressure at Crown (psi), P_{act}= 187.8
Arc length of each sector (in) = 0.4355

CIRCUMFERENCE SHORTENS= -1.06 inches

* N.A. = Neutral Axis

Pipe Crushing Calculations
10" ADS N-12

PIPE PARAMETERS - AASHTO M294, Type S

Effective Radius (in), R = 5.94
Outside Diameter (in), D = 11.36
Thickness (in), t = 0.04
Unit Area of Wall (in^2 /in), A = 0.137
Unit Moment of Inertia (in^4 /in), I = 0.0080
Flexural Modulus (psi), E_f = 110,000
Ring Compression Modulus (psi), E_{rc} = 110,000
Flexural Stiffness (psi), $K_f = 6E_fI/R^3$ = 25
Ring Compression Stiffness (psi), $K_{rc} = E_{rc}A/R$ = 2,539
Distance From Inner Wall to N.A. (in), c = 0.30

SOIL PARAMETERS - Good Granular Soil

Modulus of Soil Reaction at 5' of Cover (psi), E'_5 = 1000
Modulus of Soil Reaction (psi), E' = 4,161
Poisson's Ratio, u = 0.25
Constr Mod (psi), M*=E*(1-u)/((1+u)(1-2u))= 4992.8
Lateral Stress Ratio = K = u/(1-u) = 0.333
Sym Lateral Stress Ratio = B = (1/2)(1+K) =0.667
Antisym Lat Stress Ratio = C = (1/2)(1-K) =0.333

SOIL/STRUCTURE PARAMETERS (full slippage)

Ring Flexibility Ratio, UF =(1+K)M*/K_{rc} = 2.62
Bending Flexibility Ratio, VF = (1-K)M*/K_f = 131.9

STRESS FUNCTION COEFFICIENTS

Constant Term, a_0* = 0.351
cos(2*theta), a_2** = 0.989
sin(2*theta), b_2** = 0.983

LOAD PARAMETERS

Unit Weight of Soil (lb/ft^3) = 125
Height of Fill Above Crown (ft) = 450.0
Surcharge Pressure (psi), P = 390.6

RESPONSE OF PIPE WALL

deg c.c.w. from horiz	radial soil press P_r(psi)	radial defl w(in)	tang defl v(in)	circum wall thrust N(#/in)	wall bend mom(M) (#-lb/in)	ring comp stress (psi)	inner bend stress (psi)	outer bend stress (psi)	total stress inner (psi)	total stress outer (psi)
0	164.6	-0.292	0.000	1012	61	-7387	-2294	-1964	-9681	-9351
10	164.9	-0.251	0.118	1011	58	-7383	-2178	-1865	-9561	-9248
20	165.7	-0.131	0.222	1010	49	-7372	-1844	-1579	-9216	-8950
30	166.8	0.051	0.299	1008	36	-7355	-1331	-1140	-8687	-8495
40	168.3	0.276	0.340	1005	19	-7334	-703	-602	-8038	-7936
50	169.8	0.515	0.340	1002	1	-7312	-35	-30	-7347	-7342
60	171.2	0.739	0.299	999	-16	-7292	594	508	-6698	-6783
70	172.4	0.922	0.222	997	-30	-7275	1106	947	-6169	-6328
80	173.1	1.041	0.118	995	-39	-7264	1440	1233	-5824	-6031
90	173.4	1.083	0.000	995	-42	-7260	1556	1332	-5704	-5928
100	173.1	1.041	-0.118	995	-39	-7264	1440	1233	-5824	-6031
110	172.4	0.922	-0.222	997	-30	-7275	1106	947	-6169	-6328
120	171.2	0.739	-0.299	999	-16	-7292	594	508	-6698	-6783
130	169.8	0.515	-0.340	1002	1	-7312	-35	-30	-7347	-7342
140	168.3	0.276	-0.340	1005	19	-7334	-703	-602	-8038	-7936
150	166.8	0.051	-0.299	1008	36	-7355	-1331	-1140	-8687	-8495
160	165.7	-0.131	-0.222	1010	49	-7372	-1844	-1579	-9216	-8950
170	164.9	-0.251	-0.118	1011	58	-7383	-2178	-1865	-9561	-9248
180	164.6	-0.292	0.000	1012	61	-7387	-2294	-1964	-9681	-9351

COMMENTS

1. *This is 10" diameter ADS N-12*
2. *Flexural and compressive modulus are taken as 110,000 psi.*
3. *Typical E'_5 values (in psi) for various soils are listed in the table below:*

Type of soil	Standard AASHTO Relative Compaction 85%	90%	95%
Fine-grained soils with less than 25% sand (CL, ML, DL-ML)	500	700	1000
Coarse-grained soils with fines (SM, SC)	600	1000	1200
Coarse-grained soils with little or no fines (SP, SW, GP, GW)	700	1000	1600

CALCULATION OF RING SHORTENING

deg c.c.w. from horiz	ring comp stress (psi)	ring comp strain (in/in)	ring shortening (in)
0	-7387	-0.067152	-0.0696
10	-7383	-0.0671	-0.0695
20	-7372	-0.067018	-0.0694
30	-7355	-0.066864	-0.0693
40	-7334	-0.066677	-0.0691
50	-7312	-0.066477	-0.0689
60	-7292	-0.066289	-0.0687
70	-7275	-0.066135	-0.0685
80	-7264	-0.066035	-0.0684
90	-7260	-0.066001	-0.0684
100	-7264	-0.066035	-0.0684
110	-7275	-0.066135	-0.0685
120	-7292	-0.066289	-0.0687
130	-7312	-0.066477	-0.0689
140	-7334	-0.066677	-0.0691
150	-7355	-0.066864	-0.0693
160	-7372	-0.067018	-0.0694
170	-7383	-0.0671	-0.0695
180	-7387	-0.067152	-0.0696
		SUM (I/2 circle) =	-1.3111

Vertical deflection (%) = 18.24

Horizontal deflection (%) = -9.85
Critical Buckling Pressure (psi), P_{cr}= 122.2
Radial Soil Pressure at Crown (psi), P_{act}= 173.4
Arc length of each sector (in) = 1.0360

CIRCUMFERENCE SHORTENS= -2.62 inches

Pipe Crushing Calculations
15" ADS N-12

PIPE PARAMETERS - AASHTO M294, Type S

Effective Radius (in), R = 9.18
Outside Diameter (in), D = 17.57
Thickness (in), t = 0.150
Unit Area of Wall (in²/in), A = 0.260
Unit Moment of Inertia (in⁴/in), I = 0.054
Flexural Modulus (psi), E_f = 110,000
Ring Compression Modulus (psi), E_{rc} = 110,000
Flexural Stiffness (psi), $K_f = 6E_fI/R^3$ = 46
Ring Compression Stiffness (psi), $K_{rc} = E_{rc}A/R$ = 3,116
Distance From Inner Wall to N.A. (in), c = 0.54

SOIL PARAMETERS - Good Granular Soil

Modulus of Soil Reaction at 5' of Cover (psi), E'_5 = 1000
Modulus of Soil Reaction (psi), E' = 4,161
Poisson's Ratio, u = 0.25
Constr Mod (psi), M*=E*(1-u)/((1+u)(1-2u))= 4993
Lateral Stress Ratio = K = u/(1-u) = 0.333
Sym Lateral Stress Ratio = B = (1/2)(1+K) =0.667
Antisym Lat Stress Ratio = C = (1/2)(1-K) =0.333

SOIL/STRUCTURE PARAMETERS (full slippage)

Ring Flexibility Ratio, UF =(1+K)M*/K_{rc} = 2.14
Bending Flexibility Ratio, VF = (1-K)M*/K_f = 72.2

STRESS FUNCTION COEFFICIENTS

Constant Term, a_0* = 0.275
cos(2*theta), a_2** = 0.980
sin(2*theta), b_2** = 0.970

LOAD PARAMETERS

Unit Weight of Soil (lb/ft³) = 125
Height of Fill Above Crown (ft) = 450.0
Surcharge Pressure (psi), P = 390.6

RESPONSE OF PIPE WALL

deg c.c.w. from horiz	radial soil press P_r(psi)	radial defl w(in)	tang defl v(in)	circum wall thrust N(#/in)	wall bend mom(M) (#-lb/in)	ring comp stress (psi)	inner bend stress (psi)	outer bend stress (psi)	total stress inner (psi)	total stress outer (psi)
0	181.0	-0.495	0.000	1758	262	-6760	-2627	-1900	-9387	-8660
10	181.4	-0.432	0.181	1756	248	-6755	-2492	-1802	-9247	-8557
20	182.8	-0.249	0.340	1752	210	-6738	-2104	-1522	-8843	-8260
30	184.9	0.030	0.459	1746	150	-6714	-1510	-1092	-8224	-7806
40	187.5	0.374	0.522	1738	78	-6683	-782	-565	-7465	-7248
50	190.3	0.739	0.522	1729	1	-6651	-6	-4	-6657	-6655
60	192.8	1.082	0.459	1721	-72	-6620	723	523	-5898	-6098
70	195.0	1.362	0.340	1715	-131	-6596	1317	952	-5279	-5643
80	196.3	1.544	0.181	1711	-170	-6579	1705	1233	-4875	-5346
90	196.8	1.608	0.000	1709	-183	-6574	1839	1330	-4734	-5243
100	196.3	1.544	-0.181	1711	-170	-6579	1705	1233	-4875	-5346
110	195.0	1.362	-0.340	1715	-131	-6596	1317	952	-5279	-5643
120	192.8	1.082	-0.459	1721	-72	-6620	723	523	-5898	-6098
130	190.3	0.739	-0.522	1729	1	-6651	-6	-4	-6657	-6655
140	187.5	0.374	-0.522	1738	78	-6683	-782	-565	-7465	-7248
150	184.9	0.030	-0.459	1746	150	-6714	-1510	-1092	-8224	-7806
160	182.8	-0.249	-0.340	1752	210	-6738	-2104	-1522	-8843	-8260
170	181.4	-0.432	-0.181	1756	248	-6755	-2492	-1802	-9247	-8557
180	181.0	-0.495	0.000	1758	262	-6760	-2627	-1900	-9387	-8660

CALCULATION OF RING SHORTENING

deg c.c.w. from horiz	ring comp stress (psi)	ring comp strain (in/in)	ring shortening (in)
0	-6760	-0.061456	-0.0984
10	-6755	-0.0614	-0.0984
20	-6738	-0.061258	-0.0981
30	-6714	-0.061032	-0.0978
40	-6683	-0.060756	-0.0973
50	-6651	-0.060461	-0.0968
60	-6620	-0.060185	-0.0964
70	-6596	-0.059959	-0.0960
80	-6579	-0.059812	-0.0958
90	-6574	-0.059761	-0.0957
100	-6579	-0.059812	-0.0958
110	-6596	-0.059959	-0.0960
120	-6620	-0.060185	-0.0964
130	-6651	-0.060461	-0.0968
140	-6683	-0.060756	-0.0973
150	-6714	-0.061032	-0.0978
160	-6738	-0.061258	-0.0981
170	-6755	-0.0614	-0.0984
180	-6760	-0.061456	-0.0984
		SUM (I/2 circle) =	-1.8458

COMMENTS

1. *This is 15" diameter ADS N-12*
2. *Flexural and compressive modulus are taken as 110,000 psi.*
3. *Typical E'_5 values (in psi) for various soils are listed in the table below:*

Type of soil	Standard AASHTO Relative Compaction 85%	90%	95%
Fine-grained soils with less than 25% sand (CL, ML, DL-ML)	500	700	1000
Coarse-grained soils with fines (SM, SC)	600	1000	1200
Coarse-grained soils with little or no fines (SP, SW, GP, GW)	700	1000	1600

Vertical deflection (%) = 17.52
Horizontal deflection (%) = -10.79
Critical Buckling Pressure (psi), P_{cr}= 165.2
Radial Soil Pressure at Crown (psi), P_{act}= 196.8
Arc length of each sector (in) = 1.6017

CIRCUMFERENCE SHORTENS = -3.69 inches

Pipe Crushing Calculations
18" ADS N-12

PIPE PARAMETERS - AASHTO M294, Type S

Effective Radius (in), R = 11.014
Outside Diameter (in), D = 21.2
Thickness (in), t = 0.161
Unit Area of Wall (in^2 / in), A = 0.28
Unit Moment of Inertia (in^4 /in), I = 0.076
Flexural Modulus (psi), E_f = 110,000
Ring Compression Modulus (psi), E_{rc} = 110,000
Flexural Stiffness (psi), $K_f = 6E_fI/R^3$ = 38
Ring Compression Stiffness (psi), $K_{rc} = E_{rc}A/R$ = 2,756
Distance From Inner Wall to N.A. (in), c = 0.58

SOIL PARAMETERS - Good Granular Soil

Modulus of Soil Reaction at 5' of Cover (psi), E'_5 = 1000
Modulus of Soil Reaction (psi), E' = 4,161
Poisson's Ratio, u = 0.25
Constr Mod (psi), $M^*=E^*(1-u)/((1+u)(1-2u))$ = 4993
Lateral Stress Ratio = $K = u/(1-u)$ = 0.333
Sym Lateral Stress Ratio = B = (1/2)(1+K) = 0.667
Antisym Lat Stress Ratio = C = (1/2)(1-K) = 0.333

SOIL/STRUCTURE PARAMETERS (full slippage)

Ring Flexibility Ratio, $UF = (1+K)M^*/K_c$ = 2.42
Bending Flexibility Ratio, $VF = (1-K)M^*/K_f$ = 88.7

STRESS FUNCTION COEFFICIENTS

Constant Term, a_0^* = 0.321
cos(2*theta), a_2^{**} = 0.983
sin(2*theta), b_2^{**} = 0.975

LOAD PARAMETERS

Unit Weight of Soil (lb/ft^3) = 125
Height of Fill Above Crown (ft) = 450.0
Surcharge Pressure (psi), P = 390.6

RESPONSE OF PIPE WALL

deg c.c.w. from horiz	radial soil press P_r(psi)	radial defl w(in)	tang defl v(in)	circum wall thrust N(#/in)	wall bend mom(M) (#-lb/in)	ring comp stress (psi)	inner bend stress (psi)	outer bend stress (psi)	total stress inner (psi)	total stress outer (psi)
0	170.5	-0.561	0.000	1973	311	-7148	-2351	-1693	-9499	-8841
10	170.9	-0.484	0.218	1971	295	-7142	-2232	-1607	-9374	-8749
20	172.0	-0.264	0.410	1967	249	-7127	-1887	-1359	-9015	-8486
30	173.7	0.073	0.553	1961	180	-7104	-1360	-979	-8464	-8084
40	175.8	0.487	0.628	1953	94	-7076	-713	-513	-7789	-7590
50	178.1	0.927	0.628	1945	3	-7046	-24	-18	-7071	-7064
60	180.2	1.341	0.553	1937	-82	-7018	623	448	-6396	-6570
70	181.9	1.678	0.410	1931	-152	-6995	1150	828	-5845	-6167
80	183.0	1.898	0.218	1927	-198	-6980	1494	1076	-5486	-5904
90	183.4	1.975	0.000	1925	-213	-6975	1614	1162	-5361	-5813
100	183.0	1.898	-0.218	1927	-198	-6980	1494	1076	-5486	-5904
110	181.9	1.678	-0.410	1931	-152	-6995	1150	828	-5845	-6167
120	180.2	1.341	-0.553	1937	-82	-7018	623	448	-6396	-6570
130	178.1	0.927	-0.628	1945	3	-7046	-24	-18	-7071	-7064
140	175.8	0.487	-0.628	1953	94	-7076	-713	-513	-7789	-7590
150	173.7	0.073	-0.553	1961	180	-7104	-1360	-979	-8464	-8084
160	172.0	-0.264	-0.410	1967	249	-7127	-1887	-1359	-9015	-8486
170	170.9	-0.484	-0.218	1971	295	-7142	-2232	-1607	-9374	-8749
180	170.5	-0.561	0.000	1973	311	-7148	-2351	-1693	-9499	-8841

CALCULATION OF RING SHORTENING

deg c.c.w. from horiz	ring comp stress (psi)	ring comp strain (in/in)	ring shortening (in)
0	-7148	-0.064978	-0.1249
10	-7142	-0.0649	-0.1248
20	-7127	-0.064795	-0.1246
30	-7104	-0.064586	-0.1242
40	-7076	-0.06433	-0.1237
50	-7046	-0.064058	-0.1231
60	-7018	-0.063802	-0.1226
70	-6995	-0.063594	-0.1222
80	-6980	-0.063458	-0.1220
90	-6975	-0.063411	-0.1219
100	-6980	-0.063458	-0.1220
110	-6995	-0.063594	-0.1222
120	-7018	-0.063802	-0.1226
130	-7046	-0.064058	-0.1231
140	-7076	-0.06433	-0.1237
150	-7104	-0.064586	-0.1242
160	-7127	-0.064795	-0.1246
170	-7142	-0.0649	-0.1248
180	-7148	-0.064978	-0.1249
	SUM (I/2 circle) =		-2.3461

COMMENTS

1. *This is 18" diameter ADS N-12*
2. *Flexural and compressive modulus are taken as 110,000 psi.*
3. *Typical E'_5 values (in psi) for various soils are listed in the table below:*

Type of soil	Standard AASHTO Relative Compaction 85%	90%	95%
Fine-grained soils with less than 25% sand (CL, ML, DL-ML)	500	700	1000
Coarse-grained soils with fines (SM, SC)	600	1000	1200
Coarse-grained soils with little or no fines (SP, SW, GP, GW)	700	1000	1600

Vertical deflection (%) = 17.93
Horizontal deflection (%) = -10.18
Critical Buckling Pressure (psi), P_{cr} = 149.0
Radial Soil Pressure at Crown (psi), P_{act} = 183.4
Arc length of each sector (in) = 1.9223

CIRCUMFERENCE SHORTENS = -4.69 inches