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MEMORANDUM

TO: Paul Willman
Western Group Environmental Protection Manager
Waste Management Industries, Inc.

FROM: Tarik Hadj-Hamou, Ph.D., P.E.
Jeff Dobrowolski, P.E.
GeoSyntec Consultants

DATE: 11 February 2005

SUBJECT: **Evaluation of the Proposed Vertical Expansion Impact on Liner Design and LCRS Pipes**
Bradley Landfill, Los Angeles County, California

1. INTRODUCTION

This memorandum summarizes the evaluation conducted by GeoSyntec Consultants (GeoSyntec) of the potential effects of the proposed vertical expansion of the Bradley Landfill (BL) on the existing liner system and the existing leachate collection and recovery system (LCRS). GeoSyntec performed this scope of work at the request of Waste Management (WM).

This memorandum was prepared by Mr. Yonas Zemuy and Dr. Tarik Hadj-Hamou, P.E., and was reviewed by Mr. Jeff Dobrowolski, P.E., and Dr. Neven Matasovic, P.E., G.E., in accordance with the peer review policy of the firm.

2. BACKGROUND

It is GeoSyntec's understanding that WM is considering a vertical expansion at the BL. The vertical expansion would result in a final elevation of 1,053 ft above mean sea level (MSL). The currently permitted elevation is 1,010 ft above MSL.

The BL consists of three areas (Bradley East, Bradley West, and the Bradley West Extension) and was developed in phases starting in 1958. As a consequence of this phasing development over a 46-year period, different base liner systems have been installed at the BL.

Figure 1 shows the drain planes and lined areas at Bradley West and Bradley West Extension. This figure was developed from as-built collected by WM and GeoSyntec. Figure 1 will also serve as the base grading plan for the evaluations presented in this memorandum.

The final grading plan for elevation 1,053 ft above MSL is presented in Figure 2. This grading plan was developed by GeoSyntec for the Joint Technical Document (GeoSyntec, 2002).

Based on the base liner grading plan and the final grading plan shown in Figure 2, the maximum design column of waste is 325 ft high over the base and 70 ft high over the slope area.

3. EVALUATION OF LCRS

Based on a review of as-built liner construction documents, the LCRS consists of schedule 80 PVC pipe with an outside diameter of 4 inches (Beckhardt, 2005).

Pipe wall buckling and pipe wall crushing calculations were performed for the loading conditions outlined in the calculation package included as Attachment 1. Design values for the calculations were obtained from the following sources:

- Caltrans – Section 18 – Soil-Thermoplastic Pipe Interaction System;
- Harvel Plastic, Inc., specification tables;
- Technical Information from Link-Pipe PVC Sleeve; and

- Fax Transmittal Letter from Dave Beckhardt of BL (as-built liner drawings).

The results of these calculations indicate that the 4-inch schedule 80 PVC pipe with a SDR 11 could sustain the maximum overburden imposed by a total of 325 ft of waste (282 ft plus 43 ft added by vertical expansion).

The pipe compressive strength and the design methods and criteria were based on estimated design values obtained from several sources performed in the analysis section of this memorandum. These parameters might be slightly different for the specific pipe used at BL. However, the factors of safety against wall buckling and wall crushing calculated herein will account for uncertainty or differences in the pipe compressive strength or in the design methods and criteria.

4. EVALUATION OF EXISTING LINER

The stability of the BL waste mass and final cover system was evaluated in the Joint Technical Document (GeoSyntec, 2002). Both static and seismic loading conditions were evaluated. The stability of the final cover was also evaluated under an extreme steady-state seepage condition.

The static and seismic evaluations were conducted for a final cover elevation of 1,053 ft above MSL. The stability analyses for seismic conditions were based upon a seismic hazard analysis performed as part of the Joint Technical Document to assess the seismic loading at BL. Site-specific design ground motions were used in the seismic-site response analysis. One-dimensional seismic site response analyses were conducted in frequency domain using one-dimensional equivalent-linear model. Results of the seismic site response analyses were processed in a Newmark-type seismic deformation analysis. The results of seismic site response analyses were expressed in terms of maximum calculated permanent displacements of the waste mass and landfill cover.

Results of the static and seismic stability evaluations indicate that the proposed vertical expansion of BL to elevation 1,053 ft above MSL will meet the regulatory-mandated stability criteria. In particular, the calculated static factors of safety are in excess of 1.5 and the maximum calculated permanent seismic displacements were less than 6 inches for surfaces engaging the landfill liner and less than 3 ft for the surfaces engaging the landfill cover.

5. CONCLUSIONS

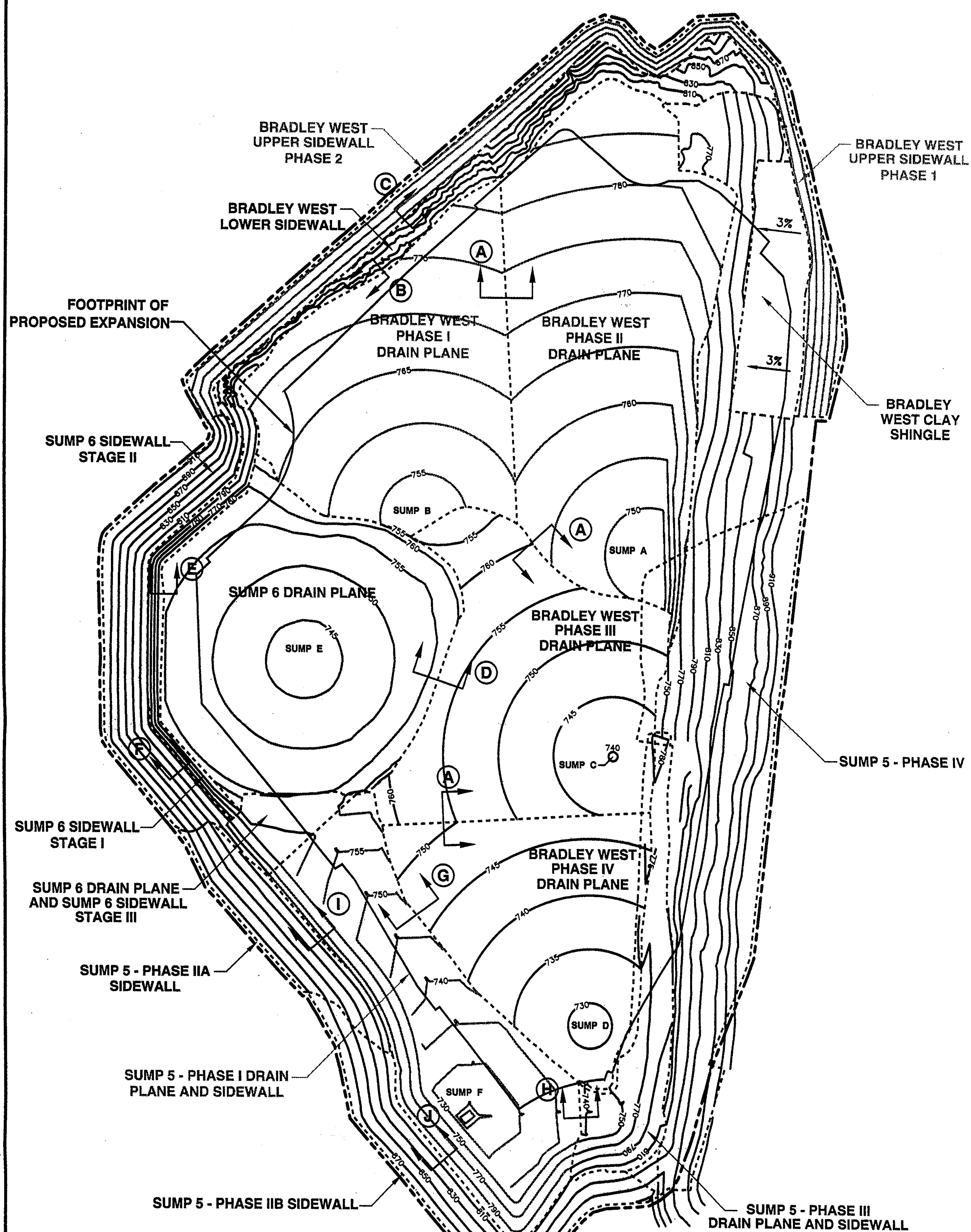
Based on a review of the existing conditions at the BL, it is concluded that the existing LCRS system can withstand the effect of the overburden pressure imposed by the proposed vertical expansion to elevation 1,053 ft above MSL. The results of the static and pseudo-static stability analyses carried out in the Joint Technical Document (GeoSyntec, 2002) indicate that static and seismic criteria (maximum allowable seismic displacement of 6 in. for landfill liner, 3 ft for landfill cover) are met.

REFERENCES

GeoSyntec (2002), "Joint Technical Document, Volumes I and II," Technical Report, GeoSyntec Consultants, Huntington Beach, California.

Beckhardt, D. (2005), Facsimile to GeoSyntec Consultants, 3 February.

* * * * *



NOTE:
THE DRAWING IS PROVIDED AS A TWO-DIMENSIONAL RENDERING, GEOSYNTEC PREPARED THE DRAWING FROM DIGITIZED HISTORICAL INFORMATION IN A "CUT-PASTE" FORMAT. GEOSYNTEC DID NOT TIE-IN CONTOUR LINES OR ADJUST ELEVATIONS BETWEEN CONTOURS.

LEGEND

- CONTOURS
- APPROXIMATE LIMITS OF PHASED LINER SYSTEM
- FOOTPRINT OF BRADLEY WEST LANDFILL

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SCHEMATIC OF LINED AREAS
BRADLEY WEST/WEST EXTENSION
SUN VALLEY, CALIFORNIA

FIGURE NO.	1
PROJECT NO.	HL0784-01
DOCUMENT NO.	
DATE:	JANUARY 2005

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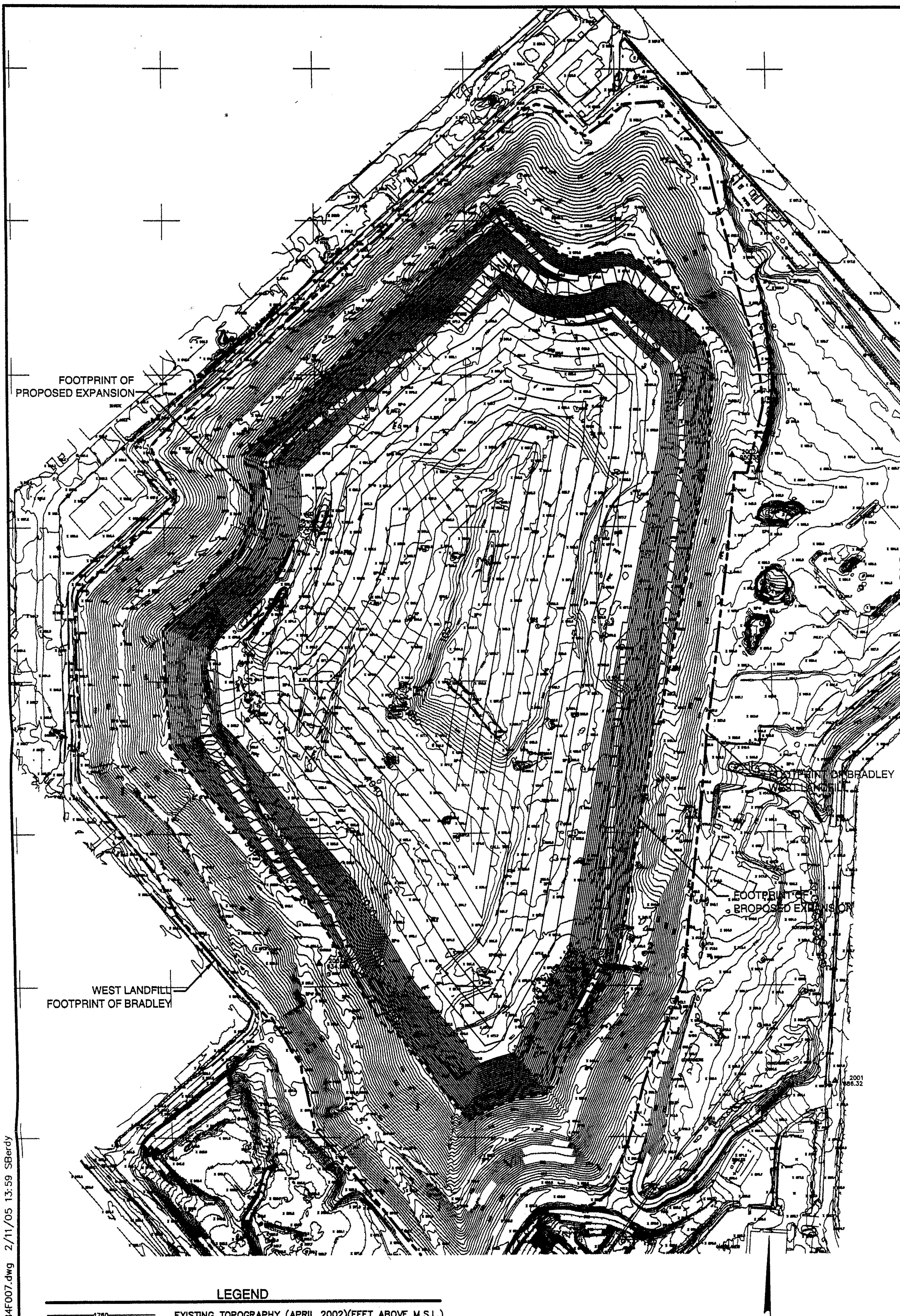

LEGEND

—1750—	EXISTING TOPOGRAPHY (APRIL 2002)(FEET ABOVE M.S.L.)
— — —	FOOTPRINT OF BRADLEY WEST LANDFILL
- - - - -	FOOTPRINT OF PROPOSED EXPANSION

GeoSyntec Consultants

FINAL COVER GRADING PLAN
BRADLEY WEST/WEST EXTENSION
SUN VALLEY, CALIFORNIA

FIGURE NO.	2
PROJECT NO.	HL0784-01
DOCUMENT NO.	
DATE:	JANUARY 2005

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ATTACHMENT 1
Calculation Package

GeoSyntec Consultants

GEOSYNTEC CONSULTANTS
COMPUTATION COVER SHEET

Client: Waste Management

Project: Bradley Landfill **Project/Proposal #:** HL0924 **Task #:** 01

Title of Computations: Pipe Strength Calculations

Computation Package: BDL-01

Computations By:

SIGNATURE — 09 February 05 DATE

Yonas Zemuy / Staff Engineer
PRINTED NAME AND TITLE

Assumptions and Procedures Checked By (Peer Reviewer):

SIGNATURE — 09 February 05 DATE

Jeffery Dobrowolski / Associate
PRINTED NAME AND TITLE

Computations Checked By:

SIGNATURE — 09 February 05 DATE

Adam King / Staff Engineer
PRINTED NAME AND TITLE

Computations Backchecked By (Originator):

SIGNATURE — 09 February 05 DATE

Yonas Zemuy / Staff Engineer
PRINTED NAME AND TITLE

Approved By (PM or Designate):

SIGNATURE — 09 February 05 DATE

Tarik Hadj-Hamou / Associate
PRINTED NAME AND TITLE

Approval Notes:

Revisions: (Number and Initial All Revisions)

No.	Sheet	Date	By	Checked By	Approval

Bradley Landfill
Pipe Strength Calculations

Over the past several years, GeoSyntec has developed a database of municipal solid waste (MSW) properties of field and laboratory investigations of the unit weight of MSW have been performed at the Asuza landfill. Profiles of the unit weight of waste versus depth at the Asuza landfill were estimated using the Spectral Analysis of Surface Waves (SASW) technique [Kavazanjian et at. 1996]. The unit weight verse depth profile of waste at the Asuza landfill is illustrated in Attachment A. Based on the reported results of the aforementioned investigations a unit weight of 85 pcf (13.3 kN/m^3) was selected for the waste for stability analysis at the Bradley landfill. This unit weight represents the average of the data for the Asuza landfill (see Attachment A).

Additional loads from equipment are assumed to be negligible due to the depth of the pipes. The maximum vertical pressure over the leachate collection pipes is calculated by:

$$P = 350 \text{ ft } (85 \text{ pcf}) / 144 \text{ in}^2/\text{ft}^2 = 206.5 \text{ psi}$$

Figure 1 & 2 ⇒ 325 ft
350 is conservative
OK
[handwritten initials]

The maximum vertical pressure over the side slope riser calculated by:

$$P = 70 \text{ ft } (85 \text{ pcf}) / 144 \text{ in}^2/\text{ft}^2 = 41.3 \text{ psi.}$$

Therefore, the vertical pressure on the top of leachate collection pipes in the long-term condition is 206.5 psi and vertical pressure over the side slope riser is 41.3 psi.

Depth of Waste	=	350 ft	(max overburden)
Depth of waste	=	70 ft	(min. overburden side slope)
Unit weight of waste	=	85 pcf	(Attachment A, page 1 of 1)

P_T	=	206.6 psi	External pressure on top of pipe, max overburden pressure
P_T	=	41.3 psi	External pressure on top of pipe, under side-slope

Analysis

E'	=	3000 psi	soil modulus for crushed rock [Philips 66 1998] (Attachment B, page 5 of 5)
P_T	=	206.6 psi	Leachate collection under max overburden pressure
P_T	=	41.3 psi	Leachate collection under side-slope pressure
E	=	140000 psi	Modulus of Elasticity for a 50-year design life [Caltrans 18 April 2000] (Attachment C, page 5 of 5)

Written by: Yonas Zemuy Date: 05 /02 /04 (YY MM DD) Reviewed by: ______ Date: 05 /02 /04 (YY MM DD)

Client: Waste Management Project: Bradley Landfill Project/Proposal No.: HL0924 Task No.: 01

SDR = D/t; Equation 1

D = outside diameter of pipe; and t = minimum pipe wall thickness

D	=	4 inch	Perforated 4-inch diameter, Schedule 80 PVC pipe [Fax from Dave Beckhardt Feb 2005] (Attachment D, page 5 of 5)
t	=	0.337 inch	[Harvel Schedule 80 PVC pipe specification tables] (Attachment E, page 2 of 2)
SDR	=	**11.87**	

Design by Wall Buckling

$F.S = P_{cb}/P_T$ = 2 Assumed factor of safety for buckling Equation 2

P_{cb} = critical buckling pressure at top of the pipe

P_T = Total soil pressure at the top of the pipe

Solving Equation 2 for the critical buckling pressure, P_{cb}, yields:

P_{cb}	=	413.2 psi	Under max overburden pressure
P_{cb}	=	82.6 psi	Under side-slope

The critical buckling pressure, P_{cb} is defined [Philips 66 1998]

P_{cb} = 0.8 * SQRT (E' * P_c) Equation 4 (Attachment B, page 2 of 5)

P_c = Critical Collapse Pressure

$P_c = [2E(t/d)^3 (D_{min}/D_{max})^3]/1-\mu^2$ Equation 5 (Attachment B, page 4 of 5)

E = pipe modulus = 140,000 psi (Attachment C, page 5 of 5)

D = Outside diameter

t = thickness

D_{min}/D_{max} =

μ = 0.415 Poisson's ratio for PVC pipe Equation 5

Equation 5 can be reduced to the following equation:

P_c = 2.32 (E)SDR^3 Equation 6 (Attachment, B page 4 of 5)

SDR^3 = 0.64*(E') * [2.32E/P_{cb}^2]

Inserting Equation 6 and rearranging, Equation 4 becomes:

SDR^3 = 0.64*(E') * [2.32E/P_{cb}^2] Equation 7

By inserting appropriate values from above, the above result is obtained:

SDR	=	15.4	Under max overburden pressure
SDR	=	45.0	Under side-slope

Written by: Yonas Zemuy Date: 05 /02 /04 (YY MM DD) Reviewed by: ______ Date: 05 /02 /04 (YY MM DD)

Client: Waste Management Project: Bradley Landfill Project/Proposal No.: HL0924 Task No.: ___

Check Wall Crushing

S = Compressive strength for PVC pipe manufactured by Harvel = 8000 psi [Link-pipe[R] PVC sleeve Attachment F page 2 of 3]

F.S = 2
F.S = S/S_A Therefore:
S_A = 4000 psi, Required compressive strength

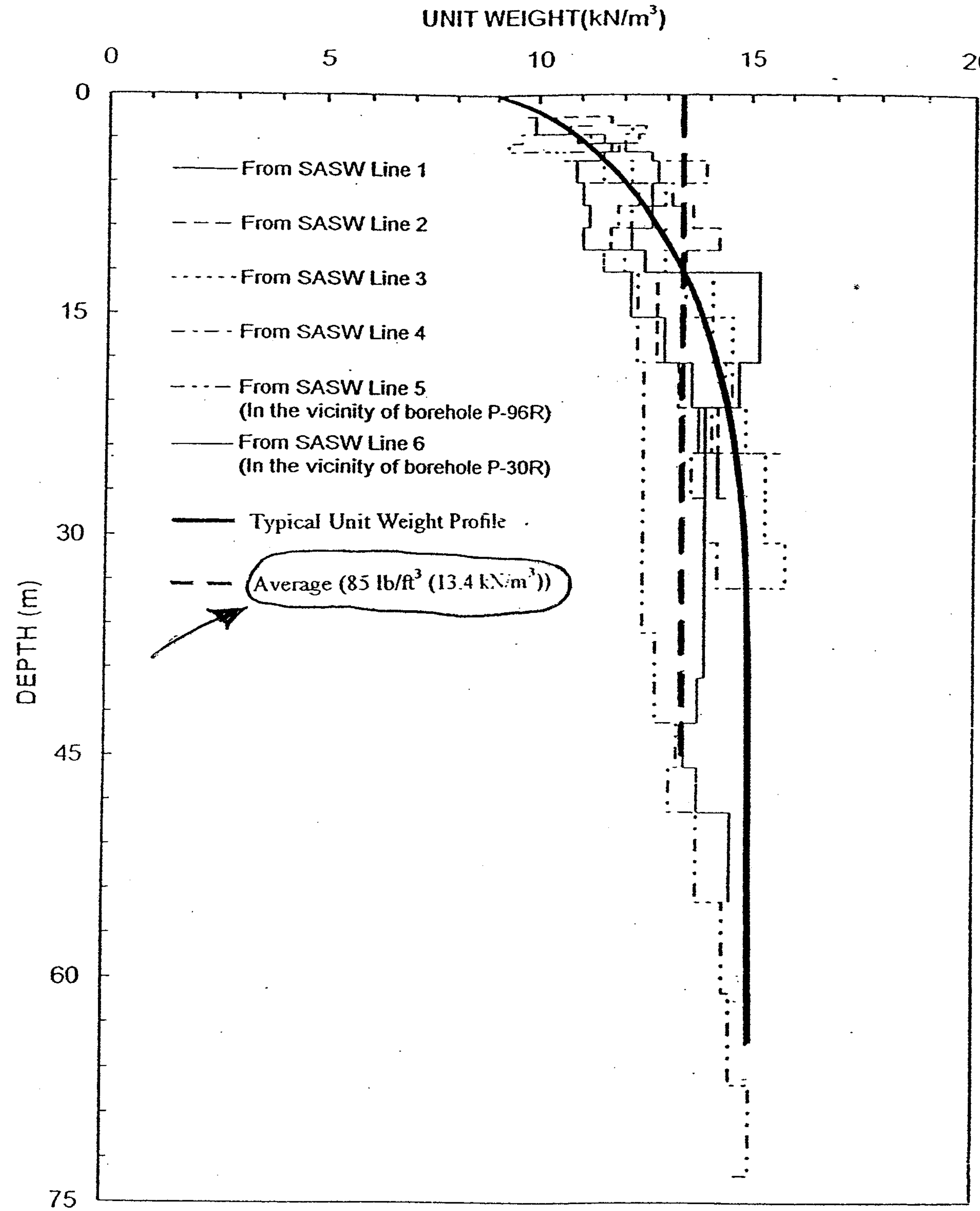
$S_A = (SDR-1)\ P_T/2$ Equation 9

P_T = 206.6 psi Under max overburden pressure
P_T = 41.3 psi Under side-slope

$SDR = [2(S_A)/P_T] + 1$ Equation 10

SDR = **39.7** Under max overburden pressure
SDR = **194.6** Under side-slope

ATTACHMENT A
Solid Waste Unit Profile



Source: Kavazanjian, et al. [1996]

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SOLID WASTE UNIT WEIGHT PROFILE BENA SANITARY LANDFILL KERN COUNTY, CALIFORNIA	FIGURE NO.	5-2
	PROJECT NO.	CE4095-GSE2
	DATE:	1 August 1999

CE4095/MODULE1/BNA99-2C.F52

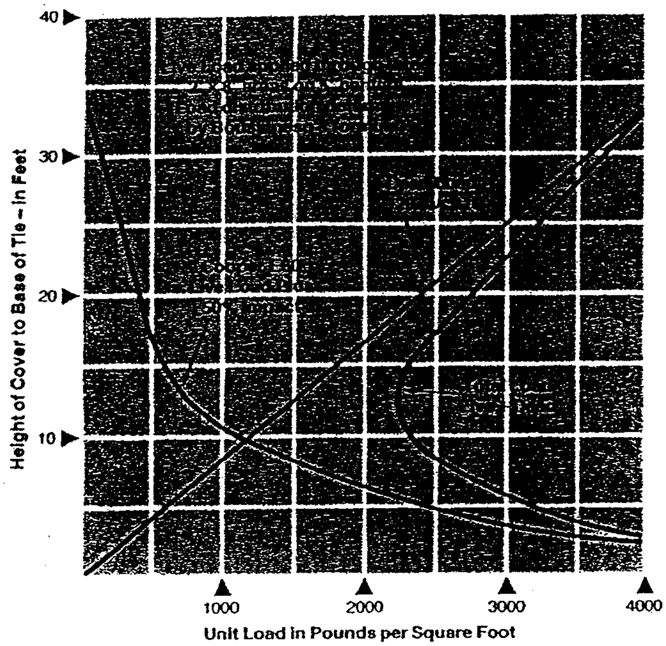
Attachment A

Page 1/1

ATTACHMENT B
Phillips Driscopipe

DRISCOPIPE®

FIGURE 6: COOPER E-80 LIVE LOADING



Note: Cooper E-80 live load assumes 80,000 pounds applied to three 2' x 8' areas on 5' centers such as might be encountered through live loading from a locomotive with three 80,000 pound axle loads.

Source: American Iron and Steel Institute, Washington, DC

APPARENT EXTERNAL PRESSURE DUE TO INTERNAL VACUUM, P_I Vacuum generates a compressive hoop stress in the wall of a pipe and acts to collapse the pipeline. Under vacuum conditions, the value of P_I is positive. P_I is added to the other two external pressure components, P_S and P_L, to obtain the total external pressure, P_T, acting on the pipe. An internal vacuum generates pressure equal to the absolute value of the vacuum. The maximum apparent external pressure due to a vacuum inside the pipe is 14.7 psi (2,117 psf).

BURIAL DESIGN GUIDELINES

The design engineer must select the proper pipe DR and specify the backfill conditions to obtain the desired performance of the "pipe-soil" system.

DESIGN BY WALL CRUSHING Wall crushing occurs when external vertical pressure causes the compressive stress in the pipe wall to exceed the long-term compressive strength of the pipe material. To design for wall crushing, the following check should be made:

$$S_A = \frac{(SDR-1)}{2} P_T$$

Where:
- S_A = Actual compressive stress, psi
- SDR = Standard Dimension Ratio
- P_T = Total external pressure on the top of the pipe, psi

Safety Factor = ~~1500~~ 1600 psi /S_A (where ~~1500~~ 1600 psi is the compressive yield strength of Driscopipe HDPE pipe) (See pg 3/5)

DESIGN BY WALL BUCKLING Local wall buckling is a longitudinal wrinkling of the pipe wall. Buckling can occur over the long term in non-pressurized pipe if the total external soil pressure, P_T, exceeds the pipe-soil system's critical buckling pressure, Pcb. Although wall buckling is seldom the limiting factor in the design of a Driscopipe system, a check of non-pressurized pipelines can be made according to the following steps to insure $P_T < P_{cb}$. All pipe diameters with the same DR in the same burial situation have the same critical collapse and critical buckling endurance.

1. Calculate or estimate the total soil pressure, P_T, at the top of the pipe.
2. Calculate the stress, S_a, in the pipe wall:

$$S_A = \frac{(SDR-1)}{2} P_T$$

3. Based upon the stress, S_a, and the estimated time duration of non-pressurization, find the value of the pipe's modulus of elasticity, E, in psi (approximate value for E is 35,000 psi).
4. Calculate the pipes hydrostatic, critical-collapse differential pressure, P_c

$$P_c = \frac{2E(t/D)^3 (D_{MIN}/D_{MAX})^3}{(1-\mu^2)} \quad \text{or} \quad P_c' = \frac{2.32(E)}{SDR^3}$$

Where:
$(D_{MIN}/D_{MAX}) = 0.95$
μ = Poission's Ratio = 0.45 for polyethylene pipe
E = stress and time dependent tensile modulus of elasticity, psi
E = 35,000 psi (approximate)
D = Outside Diameter, in.
t = thickness, in.

5 Calculate the soil modulus, E', by plotting the total external soil pressure, P_T, against a specified soil density to derive the soil strain as shown in the example problem below Figure 7.

6. Calculate the critical buckling pressure at the top of the pipe by the formula:

$$P_{cb} = 0.8\sqrt{(E')(P_c)}$$

Where:
P_{cb} = Critical buckling soil pressure at the top of the pipe, psi
E' = Soil Modulus, psi
P_c = Hydrostatic critical-collapse differential pressure, psi

7. Calculate the Safety Factor: SF = P_{cb} / P_T.
8. The above procedures can be reversed to calculate the minimum pipe DR required for a given soil pressure and an estimated soil density.

In a direct burial pressurized pipeline, the internal pressure is usually great enough to exceed the external critical-buckling soil pressure. When a pressurized line is to be shut down for a period, wall buckling should be examined.

Driscopipe® 1000

Typical Physical Properties ⊕

Property		Specification	Units	Nominal Value
Material Designation		PPI / ASTM	-	PE 3408
Material Classification		ASTM D-1248	-	III C 5 P34
Cell Classification		ASTM D-3350	-	345434C
Density	(3)	ASTM D-1505	gm / cm^3	0.955
Melt Index	(4)	ASTM D-1238 (2.16 kg/190°C)	gm / 10 min.	0.11 ♦
Flex Modulus	(5)	ASTM D-790	psi	135,000
Tensile Strength	(4)	ASTM D-638	psi	3200
ESCR	(3)	ASTM D-1693	F_0, Hours	> 5000**
HDB @ 73° F	(4)	ASTM D-2837	psi	1600
U-V Stablizer	(C)	ASTM D-1603	% C	2.5
Hardness		ASTM D-2240	Shore "D"	65
Compressive Strength (Yield)		ASTM D-695	psi	1600
Tensile Strength @ Yield (Type IV Spec.)		ASTM D-638 (2" / min)	psi	3200
Elongation @ Yield		ASTM D-638	%, minimum	8
Tensile Strength @ Break (Type IV Spec.)		ASTM D-638	psi	5000
Elongation @ Break		ASTM D-638	%, minimum	750
Modulus of Elasticity		ASTM D-638	psi	130,000
ESCR				
(Cond A,B, C: Mold. Slab)		ASTM D-1693	F_0, Hours	> 5000 **
(Compressed Ring - pipe)		ASTM F-1248	F_{50}, Hours	> 1000 **
Slow Crack Growth		Battelle Method	Days to Failure	> 64
Impact Strength (IZOD) (.125" Thick)		ASTM D-256 (Method A)	In-lb / in notch	42
Linear Thermal Expansion Coef.		ASTM D-696	in / in / ° F	1.2×10^{-4}
Thermal Conductivity		ASTM D-177	BTU - in/ ft^2 / hrs/ ° F	2.7
Brittleness Temp.		ASTM D-746	° F	< -180
Vicat Soft. Temp.		ASTM D-1525	° F	257
Heat Fusion Cond.			psi @ °F	75 @ 400

⊕ This list of Typical Physical Properties is intended for basic characterization of the pipe, and does not represent specific determinations or specifications.

** Tests were discontinued because no failures and no indication of stress crack initiation.

♦ Average Melt Index value with a standard deviation of 0.01.

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Attachment B

Where: S_A = Actual compressive stress, psi
SDR = Standard Dimension Ratio
P_T = External Pressure, psi

Safety Factor = 1500 psi ÷ S_A where 1500 psi is the Compressive Yield Strength of Driscopipe.

Design by Wall Buckling: Local wall buckling is a longitudinal wrinkling of the pipe wall. Tests of *non-pressurized* Driscopipe show that buckling and collapse do not occur when the soil envelope is in full contact with the pipe and is compacted to a dense state. However, it can be forced to occur over the long term in *non-pressurized* pipe if the total external soil pressure, P_t, is allowed to exceed the pipe-soil system's critical buckling pressure, P_{cb}. If $P_t > P_{cb}$, gradual collapse may occur over the long term. A calculated, conservative value for the critical buckling pressure may be obtained by the following approximate formula. All pipe diameters with the same SDR in the same burial situation have the same critical collapse and critical buckling endurance

$$P_{cb} = 0.8\sqrt{E' \times P_c}$$

Where:

P_t = Total vertical soil pressure at the top of the pipe, psi

P_{cb} = Critical buckling soil pressure at the top of the pipe, psi

E' = Soil modulus in psi calculated as the ratio of the vertical soil pressure to vertical soil strain at a specified density

P_C = Hydrostatic, critical-collapse differential pressure, psi

$$P_C = \frac{2E\,(t/D)^3\,(D_{MIN}/D_{MAX})^3}{(1-\mu^2)}$$

$$P_c = \frac{2.32\,E}{(SDR)^3}$$

Where: $(D_{MIN}/D_{MAX}) = .95$
μ = Poission's Ratio
μ = .45 for Driscopipe
E = stress and time dependent tensile modulus of elasticity, psi

In a direct burial pressurized pipeline, the internal pressure is usually great enough to exceed the external critical-buckling soil pressure. When a pressurized line is to be shut down for a period, wall buckling should be examined.

Design by Wall Buckling Guidelines:
Although wall buckling is seldom the limiting factor in the design of a Driscopipe system, a check of non-pressurized pipelines can be made according to the following steps to insure $P_t < P_{cb}$.

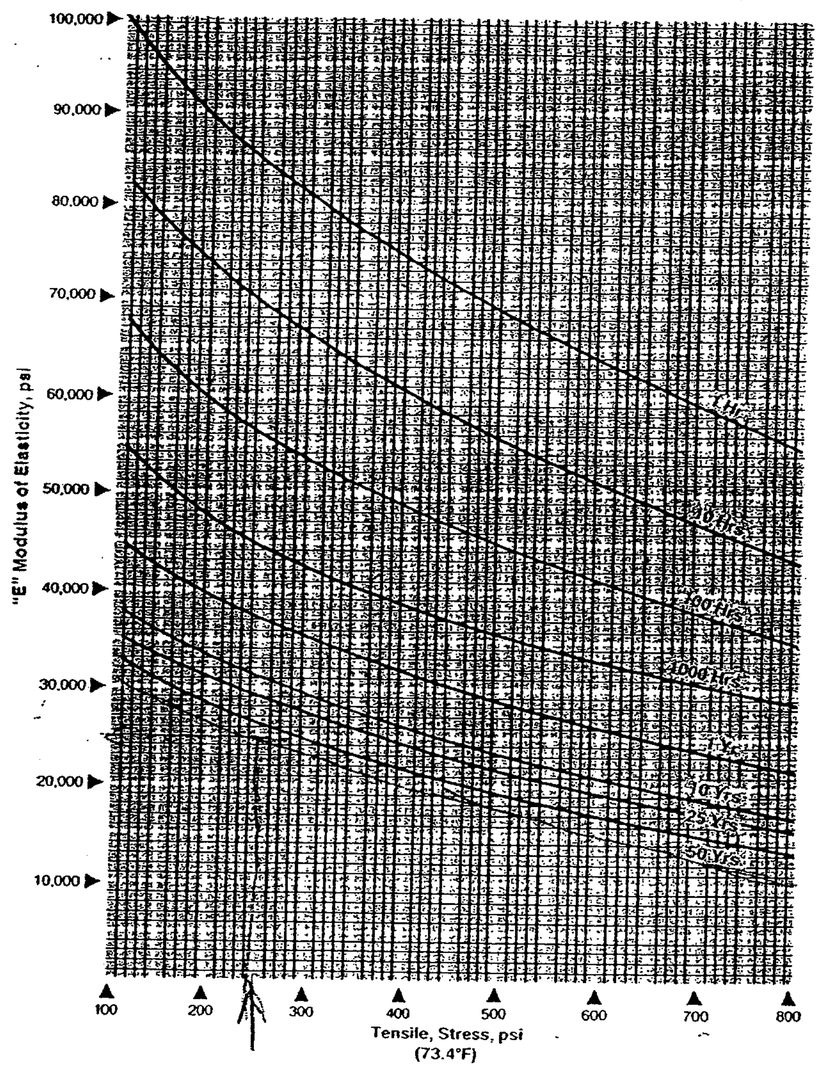
1. Calculate or estimate the total soil pressure, P_t, at the top of the pipe.
2. Calculate the stress "S_A" in the pipe wall according to the formula:

$$S_A = \frac{(SDR - 1)\,P_t}{2}$$

3. Based upon the stress "S_A" and the estimated time duration of non-pressurization, use Chart 25 to find the value of the pipe's modulus of elasticity, E, in psi.

Chart 25

Time Dependent Modulus of Elasticity for Polyethylene Pipe vs. Stress Intensity (73.4°F)



NOTE: The short term modulus of elasticity of Driscopipe per ASTM D 638 is approximately 100,000 psi. Due to the cold flow (creep) characteristic of the pipe material, this modulus is dependent upon the stress intensity and the time duration of the applied stress.

Attachment B

Page 4 of 5

TABLE 13: VALUE OF E' BASED ON SOIL TYPE (ASTM D2321) AND DEGREE OF COMPACTION

E' (psi) for Degree of Compaction (Standard Proctor Density, %)

	Soil Type of Initial Backfill Material	Loose 70%	Slight (70 - 85%)	Moderate (85- 95%)	High ≥ 95%
I	Manufactured angular, granular materials (Crushed Stone, or rock, broken coral, cinders, etc.)	1,000	3,000	3,000	3,000
II	Coarse grained soils with little or no fines		1,000	2,000	3,000
III	Coarse grained soils with fines			1,000	2,000
IV	Fine Grained Soils				
V	Organic Soils (Peat, Muck, Clay, etc.)				

Note: This summary of ASTM D 2321 is provided for the design engineer's convenience. This specification should be reviewed in detail before specifying burial conditions.

MINIMUM COVER There are no firm rules regarding minimum burial depth. The variables change for each installation, and the designer should check each design for wall crushing, wall buckling, and ring deflection. However, the following guidelines may be helpful.

- Consider a burial depth below the local frost line.
- Where there will be no overland traffic, the designer may wish to consider a cover of 18" or one diameter, whichever is greater.
- Where truck traffic may be expected, the designer may wish to consider a burial depth of 36" or one diameter, whichever is greater.
- Where heavy off-the-road truck or locomotive traffic is expected, the designer may wish to consider a minimum cover of 5 feet or more.

CALCULATION OF TOTAL SOIL PRESSURE BY COMPONENTS Proper design of the polyethylene "pipe-soil" system balances the response of the pipe and surrounding soil against the total external soil pressure. Burial design by wall crushing, wall buckling, and ring deflection require the calculation of the total soil pressure, P_T, at the top of the pipe. There are many sources of soil pressure above the pipe. It is helpful to examine the total soil pressure as the sum of its components.

ATTACHMENT C
California Transportation
(Caltrans)

SECTION 18 - SOIL-THERMOPLASTIC PIPE INTERACTION SYSTEMS

18.1 GENERAL

18.1.1 Scope

The specifications of this section are intended for the structural design of plastic pipes. It must be recognized that a buried plastic pipe is a composite structure made up of the plastic ring and the soil envelope, and that both materials play a vital part in the structural design of plastic pipe.

18.1.2 Notations

A = area of pipe wall in square inches/foot (Article 18.3.1)
B = water buoyancy factor (Article 18.3.2)
c = distance from inside surface to neutral axis (Articles 18.3.2 and 18.4.2)
D_e = effective diameter = $ID + 2c$
E = modulus of elasticity of pipe material (Articles 18.2.2 and 18.3.2)
FF = flexibility factor (Article 18.3.3)
f_{cr} = critical buckling stress (Article 18.3.2)
f_u = specified minimum tensile strength (Articles 18.3.1 and 18.3.2)
I = average moment of inertia, per unit length, of cross section of the pipe wall (Articles 18.3.2 and 18.3.3)
ID = inside diameter (Articles 18.3.2 and 18.4.2)
M_s = soil modulus (Article 18.3.2)
OD = outside diameter (Article 18.4.2)
P = design load (Article 18.1.4)
T = thrust (Article 18.1.4)
T_L = thrust, load factor (Article 18.3.1)
ϕ = capacity modification factor (Article 18.3.1)

18.1.3 Loads

Design load, *P*, shall be the pressure acting on the structure. For earth pressures see Article 6.2. For live load see Articles 3.4 to 3.7, 3.11, 3.12 and 6.3. For loading combinations see Article 3.22.

18.1.4 Design

18.1.4.1 The thrust in the wall shall be checked by two criteria. Each considers the mutual function of the plastic wall and the soil envelope surrounding it. The criteria are:

(a) Wall area
(b) Buckling stress

18.1.4.2 The thrust in the wall is:

$$T = P \times \frac{D}{2} \qquad (18\text{-}1)$$

where:
P = design load, in pounds per square foot;
D = diameter in feet;
T = thrust, in pounds per foot.

18.1.4.3 Handling and installation strength shall be sufficient to withstand impact forces when shipping and placing the pipe.

18.1.5 Materials

The materials shall conform to the AASHTO and ASTM specifications referenced herein.

18.1.6 Soil Design

18.1.6.1 Soil Parameters

The performance of a flexible culvert is dependent on soil structure interaction and soil stiffness.

The following must be considered:

(a) Soils:
(1) The type and anticipated behavior of the foundation soil must be considered; i.e., stability for bedding and settlement under load.

Attachment C page 1 of 5

(2) The type, compacted density and strength properties of the envelope immediately adjacent to the pipe must be established.

Good side fill is obtained from a granular material with little or no plasticity and free of organic material, i.e., Caltrans structure backfill compacted to a relative compaction of not less than 95%.

(3) The density of the embankment material above the pipe must be determined. A minimum of 90% shall be specified.

(b) Dimensions of envelope

The general recommended criteria for lateral limits of the culvert envelope are as follows:

(1) Trench installations – 2 feet minimum each side of culvert. This recommended limit should be modified as necessary to account for variables such as poor in-situ soils.

(2) Embankment installations – the minimum width of the soil envelope shall be sufficient to ensure lateral restraint for the buried structure. The combined width of the soil envelope and embankment beyond shall be adequate to support all the loads on the pipe. As a guide, the width of the soil envelope on each side of the pipe should be 2.0 ft minimum.

(3) The minimum upper limit of the soil envelope is 2 feet above the culvert.

18.1.7 Abrasive or Corrosive Conditions

Extra thickness may be required for resistance to abrasion. For highly abrasive conditions, a special design may be required.

18.1.8 Minimum Spacing

When multiple lines of pipes greater than 48 inches in diameter are used, they shall be spaced so that the sides of the pipe shall be no closer than one-half diameter or 3 feet, whichever is less, to permit adequate compaction of backfill material. For diameters up to and including 48 inches, the minimum clear spacing shall not be less than 2 feet.

18.1.9 End Treatment

Protection of end slopes may require special consideration where backwater conditions may occur, or where erosion and uplift could be a problem. Culvert ends constitute a major run-off-the road hazard if not properly designed. Safety treatment, such as structurally adequate grating that conforms to the embankment slope, extension of culvert length beyond the point of hazard, or provision of guardrails, is among the alternatives to be considered. End walls on skewed alignment require a special design.

18.1.10 *Deleted*

18.2 SERVICE LOAD DESIGN

Service Load Design method shall not be used.

18.3 LOAD FACTOR DESIGN

Load Factor Design is a method of design based on ultimate strength principles.

18.3.1 Wall Area

$$A = T_L/\phi f_u$$

where:

A = required area of pipe wall in square inches per foot;

T_L = thrust, load factor in pounds per foot;

f_u = specified minimum tensile strength in pounds per square inch;

ϕ = capacity modification factor.

18.3.2 Buckling

If f_{cr} is less than f_u, A must be recalculated using f_{cr} in lieu of f_u. The formula for buckling is:

$$f_{cr} = 9.24(R/A)\sqrt{BM_sEI/0.149R^3}$$

where:

B = water buoyancy factor or
= $1\text{-}0.33h_w/h$;

h_w = height of water surface above top of pipe;

h = height of ground surface above top of pipe;

E = Long term (50 year) modulus of elasticity of the plastic in pounds per square inch;

M_s = soil modulus in pounds per square inch;
= 1,700 for side fills meeting Article 18.1.6;

f_{cr} = critical buckling stress in pounds per square inch;

R = effective radius in inches;
= $c + ID/2$;

A = actual area of pipe wall in square inches/foot.

18.3.3 Handling and Installation Strength

Handling rigidity is measured by a flexibility factor, *FF*, determined by the formula:

$$FF = D_e^2 / EI$$

where:
FF = flexibility factor in inches per pound;
D_e = effective diameter in inches;
E = initial modulus of elasticity of the pipe material in pounds per square inch;
I = average moment of inertia per unit length of cross section of the pipe wall in inches to the 4th power per inch.

18.4 PLASTIC PIPE

18.4.1 General

18.4.1.1 Plastic pipe may be smooth wall, corrugated or externally ribbed and may be manufactured of polyethylene (PE) or poly (vinyl chloride) (PVC). The material specifications are:

Polyethylene (PE)

Corrugated	AASHTO M 294 Corrugated Polyethylene Pipe, 12 to 36 in. Diameter
Ribbed	ASTM 894 Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe

Poly (Vinyl Chloride) (PVC)

Profile Wall (Ribbed)	AASHTO M 304 Poly (Vinyl Chloride) (PVC) Ribbed Drain Pipe and Fittings and Based on Controlled Inside Diameter

18.4.1.2 *Deleted*

18.4.1.3 Load Factor Design – Capacity modification Factor, ϕ:

PE, $\phi = 0.9$
PVC, $\phi = 0.9$

18.4.1.4 Flexibility Factor:

PE, $FF = 9.5 \times 10^{-2}$
PVC, $FF = 9.5 \times 10^{-2}$

Note: PE and PVC are thermoplastics and, therefore, subject to reduction in stiffness as temperature is increased.

18.4.1.5 Minimum Cover

The minimum cover for design loads shall be 2 feet.

18.4.1.6 Maximum Strain

The allowable deflection of installed plastic pipe may be limited by the extreme fiber tensile strain of the pipe wall. Calculation of the tension strain in a pipe significantly deflected after installment can be checked against the allowable long-term strain for the material in Article 18.4.3. Compression thrust is deducted from deflection bending stress to obtain net tension action. The allowable long-term strains shown in Article 18.4.3 should not be reached in pipes designed and constructed in accordance with this specification.

18.4.1.7 Local Buckling

The manufacturers of corrugated and ribbed pipe should demonstrate the adequacy of their pipes against local buckling when designed and constructed in accordance with this specification.

18.4.2 Section Properties

The values given in the following tables are limiting values and do not describe actual PE or PVC pipe products. Section properties for specific PE or PVC pipe products are available from individual pipe manufacturers and can be compared against the following values for compliance.

Attachment C page 3 of 5

18.4.2.1 PE Corrugated Pipes (AASHTO M 294)

Nominal Size (in.)	Min. I.D. (in.)	Max. O.D. (in.)	Min. A (in.²/ft.)	Min. C (in.)	Min. I (in.⁴/in.)
12	11.8	14.7	1.50	0.35	0.024
15	14.8	18.0	1.91	0.45	0.053
18	17.7	21.5	2.34	0.50	0.062
24	23.6	28.7	3.14	0.65	0.116
30	29.5	36.4	3.92	0.75	0.163
36	35.5	42.5	4.50	0.90	0.222

18.4.2.2 PE Ribbed Pipes (ASTM F 894)

					Min. I (in.⁴/in.)	
Nominal Size (in.)	Min. I.D. (in.)	Max. O.D. (in.)	Min. A (in.²/ft)	Min. C (in.)	Cell Class 334433C	Cell Class 335434C
18	17.8	21.0	2.96	0.344	0.052	0.038
21	20.8	24.2	4.15	0.409	0.070	0.051
24	23.8	27.2	4.66	0.429	0.081	0.059
27	26.75	30.3	5.91	0.520	0.125	0.091
30	29.75	33.5	5.91	0.520	0.125	0.091
33	32.75	37.2	6.99	0.594	0.161	0.132
36	35.75	40.3	8.08	0.640	0.202	0.165
42	41.75	47.1	7.81	0.714	0.277	0.227
48	41.75	53.1	8.82	0.786	0.338	0.227

18.4.2.3 Profile Wall (Ribbed) PVC Pipes (AASHTO M 304)

					Min. I (in.⁴/in.)	
Nominal Size (in.)	Min. I.D. (in.)	Max. O.D. (in.)	Min. A (in.²/ft)	Min. C (in.)	Cell Class 12454C	Cell Class 12364C
12	11.7	13.6	1.20	0.15	0.004	0.003
15	14.3	16.5	1.30	0.17	0.006	0.005
18	17.5	20.0	1.60	0.18	0.009	0.008
21	20.6	23.0	1.80	0.21	0.012	0.011
24	23.4	26.0	1.95	0.23	0.016	0.015
30	29.4	32.8	2.30	0.27	0.024	0.020
36	35.3	39.5	2.60	0.31	0.035	0.031
42	41.3	46.0	2.90	0.34	0.047	0.043
48	47.3	52.0	3.16	0.37	0.061	0.056

18.4.3 Chemical and Mechanical Requirements

The polyethylene (PE) and poly (vinyl chloride) (PVC) materials described herein have stress/strain relationships that are nonlinear and time dependent. Minimum 50-year tensile strengths are derived from hydrostatic design bases and indicate a minimum 50-year life expectancy under continuous application of that tensile stress. Minimum 50-year moduli do not indicate a softening of the pipe material but is an expression of the time dependent relation between stress and strain. For each short-term increment of deflection, whenever it occurs, the response will reflect the initial modulus. Both short-term and long-term properties are shown. Except for buckling for which long-term properties are required, the judgement of the Engineer shall determine which is appropriate for the application. Initial and long-term relate to conditions of loading, not age of the installation. Response to live loads will reflect the initial modulus, regardless of the age of the installation.

18.4.3.1 Polyethylene

18.4.3.1.1 Deleted

18.4.3.1.2 Corrugated PE pipe requirements – AASHTO M 294:

Mechanical Properties for Design

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
3,000	110,000	900	22,000

Minimum cell class, ASTM D 3350, 335420C

Allowable long-term strain = 5%

18.4.3.1.3 Ribbed PE pipe requirements – ASTM F 894:

Mechanical Properties for Design

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
3,000	80,000	1,125	20,000

Minimum cell class, ASTM D 3350, 334433C
Allowable long-term strain = 5%

OR:

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
3,000	110,000	1,440	22,000

Minimum cell class, ASTM D 3350, 335434C
Allowable long-term strain = 5%

18.4.3.2 Poly (Vinyl Chloride) (PVC)

18.4.3.2.1 Deleted

18.4.3.2.2 Profile Wall (Ribbed) PVC pipe requirements – AASHTO M 304

Mechanical Properties for Design

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
7,000	400,000	3,700	140,000

Minimum cell class, ASTM D 1784, 12454C
Allowable long-term strain = 5%

OR:

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
6,000	440,000	2,600	158,400

Minimum cell class, ASTM D 1784, 12364C
Allowable long-term strain = 3.5%

ATTACHMENT D
Fax Transmittal

WASTE MANAGEMENT

Bradley Landfill and Recycling Center
9227 Tujunga Avenue
Sun Valley, CA 91352
Fax: 818/ 252-3 ____
Tel: 818/ 252-3 ____

RESENT FROM BECKHARDT CONSULTING 2/4/05 661-263-2172

FAX TRANSMITTAL COVER SHEET

- ☐ FYI
- ☐ Per Request
- ☐ Sign & Return
- ☐ Reply ASAP
- ☐ URGENT

Number of Pages to Follow: 4 (5 TOTAL)

Date: 2/3/05

Deliver To: JEFF D.
GEO SYNTEC

Fax: 1-714-969-0820

From: DAVE BECKHARDT

Subject: BRADLEY LEACHATE COLLECTION PIPES

Comments: PAGES 2+3 ARE FROM 7-16-80 AS-BUILT DWG OF SUMP A OR B OR BOTH. PAGES 4+5 ARE FROM 6/83 AND SHOW INTENTION AT THAT TIME FOR SUMP C. I BELIEVE THERE ARE NO HORIZ. PIPES FOR D AND E. HAVEN'T LOCATED ANY INFO FOR PIPES USED FOR F.

Attachment D

NO.	DATE	REVISION	BY
2	8-7-80	REV. PER D.W.P. COMMENTS & AS BUILT	JMS
1	7-24-80	GENERAL REV. PER D.W.P. COMMENTS	JMS
0	7-18-80	ISSUED FOR D.W.P. APPROVAL	JMS

CONROCK CO.
3200 SAN FERNANDO RD.
LOS ANGELES, CA. 90051

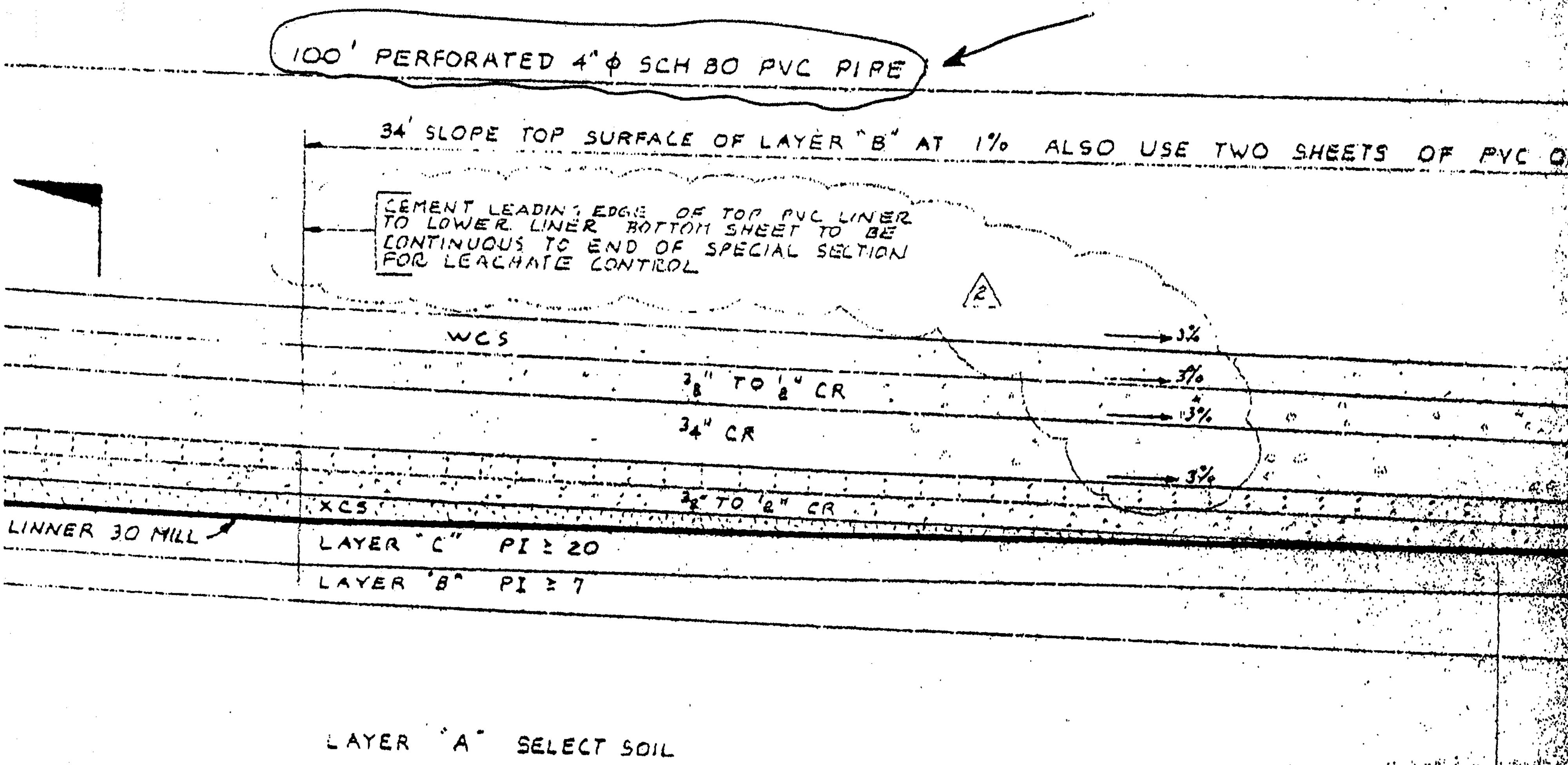
VALLEY RECLAMATION COMPANY

LEACHATE CONTROL
GRADING AT SUMP

DRN. BY	CKD. BY	DATE	SCALE	DWG. NO.	REV.
JMS		7-16-80	1/8" = 1'0" UN APPROXIMATE	22-1109-11	

Attachment D

Attachment D



SOIL SPECIFICATIONS

D&G	E	F		Filter Zone
(Percent Passing)		1/2" or	3/8"	
---	100			100
---	90 - 100	100		90 - 100
---	30 - 60	90 - 100	100	---
100	0 - 20	20 - 60	90 - 100	40 - 100
90	0 - 5	0 - 15	30 - 60	25 - 40
---	---	0 - 5	0 - 10	18 - 33
---	---	---	---	---
) - 60	---	---	---	5 - 15
---	---	---	---	---
5 - 20	---	---	---	0 - 3
---	---	---	---	---

NO.	DATE	REVISION	BY
2	7/83	ADD FILTER ZONE & MISC TOUCHUPS	AC
1	6/83	ADD NEW TABLE	AC

CONROCK CO.
3200 SAN FERNANDO RD.
LOS ANGELES, CA. 90051

PLATE 5-B

LEACHATE CONTROL GRADING AT SUMP

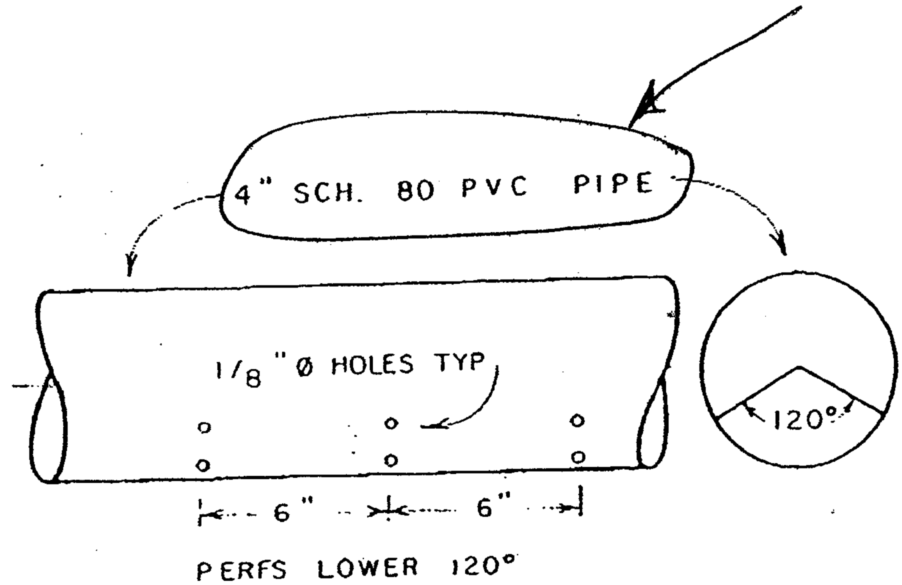
PROJ. NO. E 83076

DRN BY	CKD BY	DATE	SCALE	DWG. NO.	REV.
		6/83	AS SHOWN	22-1109-17	

ALL AND ASSOCIATES

Attachment D

 10.249 HISTORICAL



COLLECTOR PIPE PERFORATION DETAIL

Tr. SUMP
E COMPACTED
D1557-70

1

SOIL SPECIFICATIONS

Sieve Size	Layers: B	C	D & G	E	I
	(Percent Passing)				
1-inch	---	---	---	100	
3/4-inch	---	---	---	90 - 100	10C
1/2-inch	---	---	---	30 - 60	90 -
3/8-inch	---	---	100	0 - 20	20 -
No. 4	---	---	90	0 - 5	0 -
No. 8	---	---	---	---	0 -
No. 10	---	100	---	---	--
No. 30	---	---	20 - 60	---	--
No. 40	90	90	---	---	--
No. 200	65	65	5 - 20	---	--
P.I.*(min.)	7	20	---	---	--

(*) P.I. = Plasticity Index

Attachment D

ATTACHMENT E
Harvel Plastic, Inc

Quality. Innovation. Reliability.

Technical Support

PVC Pipe

Superior Quality Piping for a Wide Range of Applications

SCHEDULE 40 & 80 - DIMENSIONS

Schedule 40 Dimensions

Nom. Pipe Size (in)	O.D.	Average I.D.	Min. Wall	Nom. Wt./Ft.	Max. W.P. PSI**
1/8"	0.405	0.249	0.068	0.051	810
1/4"	0.540	0.344	0.088	0.086	780
3/8"	0.675	0.473	0.091	0.115	620
1/2"	0.840	0.602	0.109	0.170	600
3/4"	1.050	0.804	0.113	0.226	480
1"	1.315	1.029	0.133	0.333	450
1-1/4"	1.660	1.360	0.140	0.450	370
1-1/2"	1.900	1.590	0.145	0.537	330
2"	2.375	2.047	0.154	0.720	280
2-1/2"	2.875	2.445	0.203	1.136	300
3"	3.500	3.042	0.216	1.488	260
3-1/2"	4.000	3.521	0.226	1.789	240
4"	4.500	3.998	0.237	2.118	220
5"	5.563	5.016	0.258	2.874	190
6"	6.625	6.031	0.280	3.733	180
8"	8.625	7.942	0.322	5.619	160
10"	10.750	9.976	0.365	7.966	140
12"	12.750	11.889	0.406	10.534	130
14"	14.000	13.073	0.437	12.462	130
16"	16.000	14.940	0.500	16.286	130
18"	18.000	16.809	0.562	20.587	130
20"	20.000	18.743	0.593	24.183	120
24"	24.000	22.544	0.687	33.652	120

Schedule 80 Dimensions

Nom. Pipe Size (in)	O.D.	Average I.D.	Min. Wall	Nom. Wt./Ft.	Max. W.P. PSI**
1/8"	.405	.195	0.095	0.063	1230
1/4"	.540	.282	0.119	0.105	1130

Attachment E

Page 1 of 2

3/8"	.675	.403	0.126	0.146	920
1/2"	.840	.526	0.147	0.213	850
3/4"	1.050	.722	0.154	0.289	690
1"	1.315	.936	0.179	0.424	630
1-1/4"	1.660	1.255	0.191	0.586	520
1-1/2"	1.900	1.476	0.200	0.711	470
2"	2.375	1.913	0.218	0.984	400
2-1/2"	2.875	2.290	0.276	1.500	420
3"	3.500	2.864	0.300	2.010	370
3-1/2"	4.000	3.326	0.318	2.452	350
4"	4.500	3.786	0.337	2.938	320
5"	5.563	4.768	0.375	4.078	290
6"	6.625	5.709	0.432	5.610	280
8"	8.625	7.565	0.500	8.522	250
10"	10.750	9.493	0.593	12.635	230
12"	12.750	11.294	0.687	17.384	230
14"	14.000	12.410	0.750	20.852	220
16"	16.000	14.213	0.843	26.810	220
18"	18.000	16.014	0.937	33.544	220
20"	20.000	17.814	1.031	41.047	220
24"	24.000	21.418	1.218	58.233	210

Attachment E

ATTACHMENT F
Link-Pipe – PVC Sleeve

Link-Pipe Inc.-Manufacturer of No-Dig Pipe Repair Products. ISO 9001-2000 Registered Company

Link-Pipe sewer
Drinking quality
LINK-PIPE® is
LINK-PIPE®
Pressure Pipes
Industrial
Gas Sealer
Drain Liner is a
Water Wells

Find detailed information about Link-Pipe products.
--Product List--

Find detailed information about restoration and installation equipment
--Equipment--

Find detailed information about....
We are looking
Link-Pipe
PLEASE READ
Link-Pipe Inc. is

LINK-PIPE® PVC Sleeve

Worker-Accessible Installation

Structural repair and sealing infiltration in sewer pipes, collector mains and culverts without stopping flow.

Designed to last 100 years
10-Year Limited Warranty

TECHNICAL INFORMATION

The Use of LINK-PIPE® PVC Sleeve

Repairs
- longitudinal cracks
- circumferential cracks
- multiple cracks
- broken pipes
- laterals
- closes holes

Other Applications
- Reinstates partially collapsed pipes
- Recreates a totally collapsed or missing pipe
- Recreates continuity over separated joints,

Search F

Installation Instruction
LINK-PIPE® PV(Sleeve specification
Structural Stren calculation
Culvert repair w LINK-PIPE® PV(Sleeve
Grout G-101 MS
Grout G-200 MS
Installation Equipment
PVC Sleeve vide click here

LINK-PIPE® PV

(click to enl

To find out m(LINK-PIPE®PV Sleeve call us 1-800-265-56

Attachment F page 1 of 3

Accommodates misaligned and offset joints
Seals infiltration of gravity flow pipes
Seals ex-filtration of gravity flow pipes
Seals abandoned services
Retards root growth
Repairs sewer pipe without closing service laterals

DIMENSIONS:

LINK-PIPE® PVC Sleeves are available in diameters ranging from 36" (900mm) to 108" (2800mm) with standard lengths of 18" (450mm), 24" (600mm) and 36" (900mm)

LINK-PIPE® PVC SLEEVE IN STANDARD FORM:

- **PVC core:** Manufactured from rigid polyvinyl chloride, LINK-PIPE® PVC Repair Sleeves usually consist of six segments. The edges are designed to lock each segment in place.

LINK-PIPE® PVC sleeve core material conforms to "PVC 12454-B" material properties:

Tensile strength @ 73° F (23°C)	ASTM, D 638	7940 psi
Compressive strength @ 73° F (23°C)	ASTM, D 695	8000 psi
Flexural strength @ 73° F (23°C)	ASTM, D 790	14,500 psi
Water absorption in 24 hrs @ 73° F (23°C)	ASTM, D 570	0.05%
Modulus of Elasticity in Tension @ 73° F (23°C)	ASTM, D 638	4.2×10^5 psi

- **Grouts**: Polyurethane grout is used to fill annular space between the sleeve and host pipe when the repaired pipe is required to retain flexibility. Grout **G-200** is used for structural repair and grout **G-101** is used for or sealing infiltration.

NOTE: Cement grout offers an economic alternative when joint flexibility is not required

- **O-rings:** The O-ring materials such as neoprene natural rubber, viton may be specified to suit a wide range of chemical environments.

STRENGTH:

LINK-PIPE® Wall thickness of the sleeve is selected to meet structural requirements specified by the customer. A minimum design load of 10-psi is recommended. If higher working load calls for increased wall thickness.

Attachment F

For structural strength calculation click here

Service Life:
PVC material used in making LINK-PIPE® PVC Sleeves has been used in pressure main construction for 50 years without any sign of chemical or structural breakdown. From this record and laboratory tests for chemical resistance a minimum 100-year service life for these sleeves is anticipated.

QUALITY CONTROL:

Manufacturing follows ISO 9001-2000 certified Quality Control procedures.

Written Quality Control standards required for installation are contained in each sleeve shipping container. (See Step #6 Installation Tips)

WARRANTY:
Manufacturer offers a 10-Year Limited Warranty.

Below are the links for the web sites where Caltrans (California Department of Transportation) and FHWA (Federal Highway Administration) specified the LINK-PIPE® PVC Sleeve and GROUTING SLEEVE™ for the internal culvert repair.
"Culvert Repair Manual" volume 1 (FHWA)
http://olpweb01.dot.gov/olpfiles/fhwa/010551.pdf
"Culvert Repair Manual" volume 2 (FHWA)
http://olpweb01.dot.gov/olpfiles/fhwa/010550.pdf
DIB 83 - Caltrans Supplement to FHWA "Culvert Repair Practices" Manual
http://www.dot.ca.gov/hq/oppd/culvert/

For specification click here
For installation equipment click here
For installation tips click here
References click here
PVC Sleeve video click here (Size: 3 parts, 600 KB each)

Attachment F

page 3 of 3