Written by: Steve Fitzwilliam Date: 05 / 10 / 21 (YY MM DD) Reviewed by: Greg Corcoran Date: __ / __ / __ (YY MM DD)

Client: Slough Project: Britannia East Grand Project/Proposal No.: SC0347 Task No.: 1

PIPE HANGER DESIGN

OBJECTIVE

At the proposed Britannia East Grand development site in South San Francisco, California, pipe hangers suspended from the concrete structural slab will support the air inlet and gas extraction pipes beneath the buildings at the Site. The pipe hangers will be installed during the construction of the gas control system.

The design of the pipe hangers takes into consideration two controlling factors; the spacing of the pipe hangers such that the pipes do not deflect more than 1", which is half the diameter of the pipe, and the maximum allowable load each pipe hanger can support.

SUMMARY OF ANALYSIS

The analysis suggests that the pipe hangers used for this project need to support at least 45 lbs. if there is 1 inch of soil located between the top of the pipe and the concrete slab. In addition, the pipe hangers need to be spaced approximately 8 ft. apart such that the PVC air inlet and gas extraction pipes do not deflect more than 1".

SITE CONDITIONS

The components involved in this analysis are the following, from top to bottom:

- 10 inches of structural concrete slab;
- protection course (a nonwoven needle-punched cushion geotextile);
- 80 mil Liquid Boot geomembrane;
- heat bonded nonwoven carrier geotextile;
- 3 to 6 inches of gas extraction sand and aggregate; and
- 2-inch diameter PVC pipe.

A cross-section of the gas control system is presented as Attachment A.

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ANALYSIS

- **PIPE HANGER SPACING**

The spacing of the pipe hangers is controlled by the maximum allowable deflection of the pipe. The deflection of the pipe is due to the weight of the pipe itself (Attachment B), as well as the weight of the soil on top of the pipe. Depending on the type of pipe hanger selected, soil may be located between the pipe and the bottom of the concrete slab. For the purposes of this analysis, it is assumed that 1 inch of soil will separate the top of the PVC pipe and the concrete structural slab.

The equation used to calculate deflection for a distributed load is:

$$v_{\max} = \left(\frac{5}{384}\right)\frac{qL^4}{EI}$$ (Attachment C)

Where: v_{max} = maximum deflection (inches)
q = distributed applied loading (pounds/inches)
L = length of pipe (inches)
E = modulus of elasticity (pounds/inches^2)
I = moment of Inertia (inches^4)

EVALUATE EQUATION

v_{max} = 1" - (to allow air flow if water infiltrates pipe)

q = weight of pipe + weight of soil on top of pipe

Weight of pipe = 0.695 lb/ft = 0.058 lb/in (Attachment B)

Weight of soil = (d)(ϕ)(γ_{soil})

where: d = depth of pipe, assumed to be 1"
ϕ = outside width of pipe = 2.375"
γ_{soil} = unit weight of soil, assumed to be 125 lbs/ft^3

Weight of soil = (1 in.)(2.375 in.)(125 lbs/ft^3)(1 ft^3/1728 in^3) = 0.172 lb/in

q = 0.058+ 0.172 = 0.230 lb/in

E = 400,000 lb/in^2 (Attachment D)

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$I = 0.666\ in^4$ (Attachment E)

Plugging in the variables,

$$v_{max} = \left(\frac{5}{384}\right)\frac{qL^4}{EI}$$

$$1" = \left(\frac{5}{384}\right)\frac{0.230 lb/in * L^4}{(400{,}000 lb/in^2) * 0.666 in^4}$$

L = 97.1 in = 8.1 ft.

Therefore, the pipe hangers should be spaced every eight (8) feet.

- **PIPE HANGER STRENGTH**

The maximum load each pipe hanger should be able to support is equal to the weight of the PVC pipe and overlying soil over the distance between pipe hangers, plus a factor of safety of 2.0. Therefore, each pipe hanger for pipe 1 inch deep should be able to support:
(0.230 lbs/in)*[(8 ft.)(12 in./ft)]* (2.0) = 45 lbs.

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CONCLUSIONS

Assuming the following:

- the maximum allowable deflection of the PVC pipe is 2 inches; and
- 1 inch of soil are located between the top of the pipe and the concrete slab.

The pipe hangers should be spaced 8 ft. apart for solid wall pipes. In addition, the pipe hangers need to support a maximum load of 45 lbs. Perforated pipes will drain, so no hangers required.

- **PIPE HANGERS THAT MEET REQUIREMENTS**

The following is a partial list of pipe hangers that meet the property values stated above:

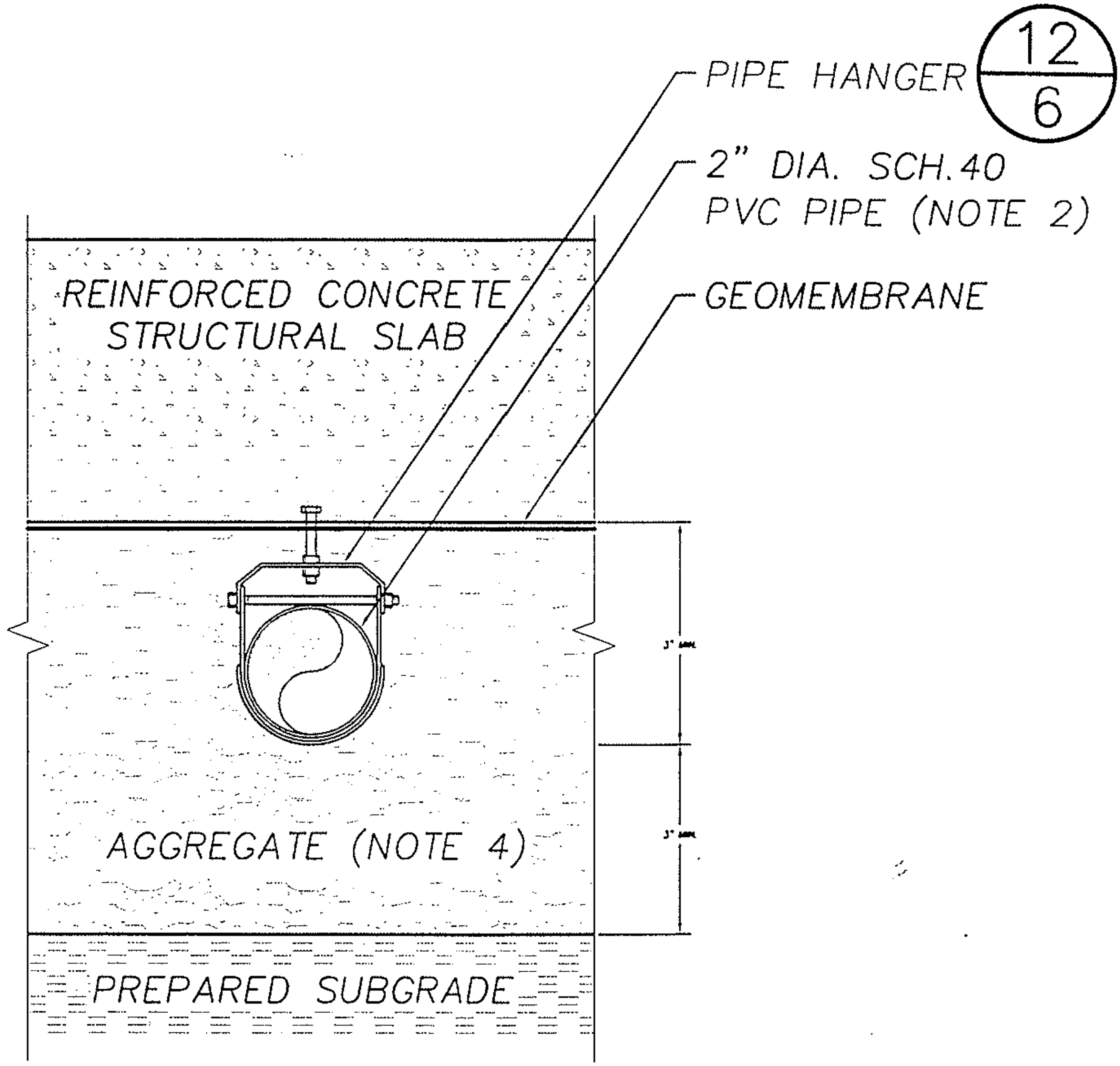
- Standard Clevis 4" Hanger, with a work load limit of 1430 lbs.

REFERENCES

ASTM D 1784 – 92 "Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Compounds and Chlorinated Poly (Vinyl Chloride) (CPVC) Compounds", American Society for Testing and Materials, Philadelphia, Pennsylvania, USA

Harrington, PVC Pipe – Schedule 40 Properties

Sack, R.L. (1984) "Structural Analysis," McGraw-Hill, Inc., New York.



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1,5

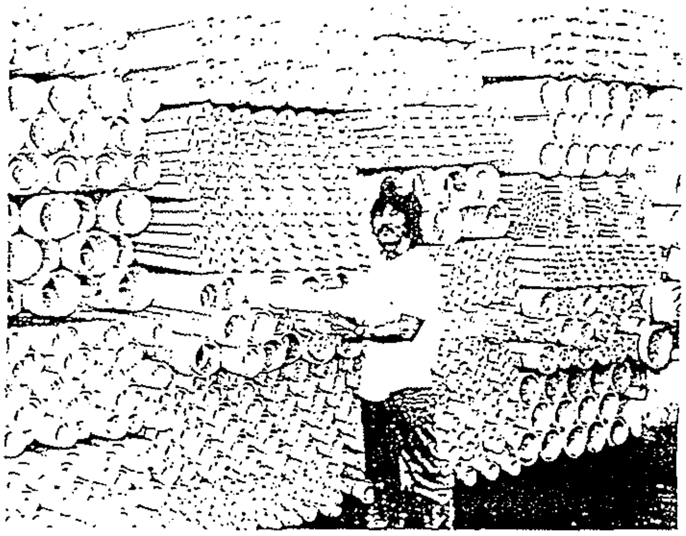
SECTION
GAS EXTRACTION SYSTEM

N.T.S.

PVC PIPE - SCHEDULE 40

1 PIPE AND FITTINGS

PVC is the most frequently specified of all plastic piping materials. It has been used successfully for over 30 years in such areas as chemical processing, industrial plating, chilled water distribution, deionized water lines, chemical drainage, DWV piping, and irrigation systems. PVC is characterized by high physical properties and resistance to corrosion and chemical attack by acids, alkalies, salt solutions and many other chemicals.



PVC used in plastic piping is:
- Type 1, Grade 1 PVC (Cell Classification 12454-B)
- Conforms to ASTM D-1784

The maximum service temperature for PVC is 140°F. PVC has the highest long term hydrostatic strength at 73°F of any of the major thermoplastics being used for piping. PVC piping is joined by solvent cementing or threading.

SCHEDULE 40 PVC PIPE - Conforms to ASTM D-1785, Type 1 (normal impact), Grade 1 (high chemical resistance). This pipe also conforms to U.S. Product Standard PS 21-70 (supersedes U.S. Commercial Standard CS 207-60) as having the same O.D. dimensions as iron pipe. The National Sanitation Foundation (NSF) has approved pipe sizes 1/4" thru 12" for use in potable water service. Schedule 40 pipe should not be threaded.

NOMINAL[1] PIPE SIZE (IN.)	PART NUMBER	PRICE PER 100 FT. ($)	APPROX. WT/100 FT.	MAX. W.P. @ 73.4°F	OUTSIDE DIA. (IN.)	MINIMUM WALL THICKNESS (IN.)
1/4[2]	400-002	98.00	8.1	780	.540	.088
3/8[2]	400-003	131.00	10.9	620	.675	.091
1/2	400-005	67.00	16.4	600	.840	.109
3/4	400-007	89.00	21.6	480	1.050	.113
1	400-010	132.00	32.1	450	1.315	.133
1-1/4	400-012	177.00	43.4	370	1.660	.140
1-1/2	400-015	212.00	51.8	330	1.900	.145
2	400-020	284.00	69.5	280	2.375	.154
2-1/2	400-025	451.00	109.6	300	2.875	.203
3	400-030	583.00	143.5	260	3.500	.216
3-1/2[2]	400-035	1,814.00	169.7	240	4.000	.226
4	400-040	830.00	204.3	220	4.500	.237
5	400-050	1,127.00	272.6	190	5.563	.258
6	400-060	1,459.00	360.9	180	6.625	.280
8	400-080	2,643.00	545.3	160	8.625	.322
10	400-100	3,226.00	791.3	140	10.750	.365
12	400-120	4,265.00	1053.2	130	12.750	.406
14[4]	400-140	5,300.00	1247.0	130	14.00	.437
16[4]	400-160	7,106.00	1675.0	130	16.00	.500
18[4]	400-180	10,887.00	2111.0	130	18.00	.562
20[4]	400-200	12,793.00	2490.0	130	20.00	.593
24[4]	400-240	16,507.00	3451.0	130	24.00	.687

NOTES: 1. Standard length 20 feet. 2. Pipe sizes 1/4", 3/8" and 3-1/2" are gray in color. All other pipe is normally white. 3. Pipe may be plain or belled end. 4. 14" and 24" pipe has been approved by the Canadian Standards Association (CSA) for potable water service.

WARNING: DO NOT TEST OR USE PVC PIPING FOR AIR OR COMPRESSED GASES.

Attachment G

Therefore, $$C_1 = -M_1 L \qquad C_2 = \tfrac{1}{2} M_1 L^2$$

$$EIv = \tfrac{1}{2} M_1 (x^2 - 2Lx + L^2) \qquad EI\frac{dv}{dx} = M_1(x - L)$$

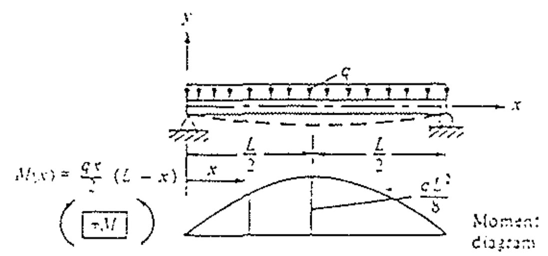
At the free end

$$v_{max} = 0.12 \text{ in } (\uparrow)$$

$$\left(\frac{dv}{dx}\right)_{max} = -0.0016 \text{ rad} = -0.09^\circ \;(\frown)$$

DISCUSSION This is the same beam as in Example 9.2, but it is loaded with a concentrated moment at the free end. In this case, the moment deforms the beam into a positive curvature over the entire length. The same geometric-compatibility conditions used in Example 9.2 were used here to evaluate the integration constants. The maximum deflection of 0.12 in occurs at the free end, where the maximum slope of −0.0016 also occurs.

Example 9.4 Find the maximum deflection and slope for this simply supported beam.



$L = 12$ m
$E = 200$ GPa
$I = 4 \times 10^3$ mm^4
$q = 5$ kN/m

Figure E9.4

SOLUTION

$$EI\frac{d^2v}{dx^2} = M$$

$$EI\frac{dv}{dx} = -\tfrac{1}{6}qx^3 + \tfrac{1}{4}qLx^2 + C_1$$

$$EIv = -\tfrac{1}{24}qx^4 + \tfrac{1}{12}qLx^3 + C_1x + C_2$$

$$v(0) = 0 \qquad v(L) = 0$$

Hence, $$C_1 = -\tfrac{1}{24}qL^3 \qquad C_2 = 0$$

$$EIv = \tfrac{1}{24}qx(-x^3 + 2Lx^2 - L^3)$$

$$EI\frac{dv}{dx} = \tfrac{1}{24}q(-4x^3 + 6Lx^2 - L^3)$$

Since $M = 0$ at $x = 0$ and $x = L$, the slope has the maximum magnitudes at these points. Since $dv/dx = 0$ at $x = \tfrac{1}{2}L$, v_{max} occurs there.

From: Sack, 1984

$$v_{max} = \frac{5}{384}\frac{qL^4}{EI} = \frac{5}{384}\frac{5(12^4)}{(200 \times 10^9)(4 \times 10^{-4})} = 16.88 \times 10^{-3}\ \text{m}$$

$$\left(\frac{dv}{dx}\right)_{max} = \frac{qL^3}{24EI} = \frac{5(12^3)}{24(200 \times 10^9)(4 \times 10^{-4})} = 4.5 \times 10^{-3}\ \text{rad} = 0.26°$$

DISCUSSION This symmetric beam is bent into positive curvature over its entire length by the uniform loading. The zero deflections at the two supports are used to evaluate the constants of integration. The deflection expression turns out to be a quartic polynomial with the maximum deflection occurring at $x = L/2$; the slope has its maximum magnitude at both supports and a zero value at $x = L/2$. The dimensions and size of the steel beam shown result in a maximum deflection of 16.88 mm with a maximum magnitude of slope equal to 0.26° at the two supports.

This method is more complex for a beam with a loading like that shown in Fig. 9.5. In this case the moment expression for the moment between points a and b differs from that for the moment between points b and c; therefore, the moment-curvature relation must be integrated individually for each segment. This process gives four constants of integration to describe the beam displacements. Two of these constants can be evaluated by enforcing the conditions of zero displacement at the supports, and the other two must be evaluated by matching the expressions at point b for the slope and deflection. Since there are more elegant mathematical ways of obtaining the expressions for displacement and slope for these types of problems, the reader who intends to use this method extensively would be wise to study the application of singularity functions to these problems (see for example, Ref. 2).

9.4 THE PRINCIPLE OF SUPERPOSITION

If a structure is acted upon by a number of individual forces and/or moments, the total deflection of the structure can be obtained by calculating the deflections induced by each of the individual forces and adding the results. This process of combining solutions for a given problem is called *superposition*, and the validity of the approach depends upon the linearity of the structure. Figure 9.6a and 9.6b shows load-deformation graphs for a linear and a nonlinear structural response, respectively. We can see that for the linear structure an applied load P will give the deformation Δ regardless of where in the loading process it is applied. For the nonlinear situation the same load P will give different deformations, Δ_1 and Δ_2, which depend upon the amount of loading previously applied to the structure. Nonlinearities can be introduced

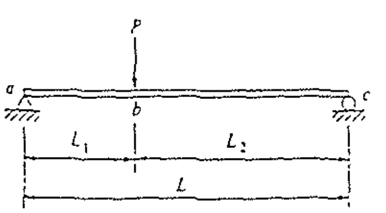


Figure 9.5 Beam with an applied concentrated force.

Attachment C 2/7

: following

IL	AQL
	2.5
2	2.5
1	1.5
1[4]	...

nd pooled for
t.

Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds[1]

This standard is issued under the fixed designation D 1784; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This specification covers rigid PVC and CPVC compounds intended for general purpose use in extruded or molded form, including piping applications involving special chemical and acid resistance or heat resistance, composed of poly(vinyl chloride), chlorinated poly(vinyl chloride), or vinyl chloride copolymers containing at least 80 % vinyl chloride, and the necessary compounding ingredients. The compounding ingredients may consist of lubricants, stabilizers, non-poly(vinyl chloride) resin modifiers, pigments and inorganic fillers.

NOTE 1—Selection of specific compounds for particular end uses or applications requires consideration of other characteristics such as thermal properties, optical properties, weather resistance, etc. Specific requirements and test methods for these properties shall be by mutual agreement between the purchaser and the seller.

1.2 Rigid PVC compounds intended for pipe, fittings and other piping appurtenances are covered in Specifications D 3915 and D 4396.

1.3 Rigid PVC compounds intended for building product applications are covered in Specification D 4216.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 The following safety hazards caveat pertains only to the test methods portion, Section 11, of this specification: *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 2—This specification is similar in content (but not technically equivalent) to ISO 1163-1:1985 and ISO 1163-2:1980.[2]

2. Referenced Documents

2.1 *ASTM Standards:*

- D 256 Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials[3]
- D 471 Test Method for Rubber Property—Effect Liquids[4]
- D 543 Test Method for Resistance of Plastics to Chemic Reagents[3]
- D 618 Practice for Conditioning Plastics and Electric Insulating Materials for Testing[3]
- D 635 Test Method for Rate of Burning and/or Extent ar Time of Burning of Self-Supporting Plastics in a Ho zontal Position[3]
- D 638 Test Method for Tensile Properties of Plastics[3]
- D 648 Test Method for Deflection Temperature of Plasti Under Flexural Load[3]
- D 790 Test Methods for Flexural Properties of Unrei forced and Reinforced Plastics and Electrical Insulatir Materials[3]
- D 883 Terminology Relating to Plastics[3]
- D 1600 Terminology for Abbreviated Terms Relating t Plastics[3]
- D 1898 Practice for Sampling of Plastics[5]
- D 1921 Test Methods for Particle Size (Sieve Analysis) c Plastic Materials[5]
- D 3892 Practice for Packaging/Packing of Plastics[5]
- D 3915 Specification for Poly(Vinyl Chloride) (PVC) ar Related Plastic Pipe and Fitting Compounds for Pre sure Applications[7]
- D 4216 Specification for Rigid Poly(Vinyl Chloride) (PVC and Related Plastic Building Products Compounds[7]
- D 4396 Specification for Rigid Poly(Vinyl Chloride) (PVC and Related Plastic Compounds for Non-Pressure Pip ing Products[7]
- D 5260 Classification for Chemical Resistance of Poly (Vinyl Chloride) (PVC) Homopolymer and Copolyme Compounds and Chlorinated Poly(Vinyl Chloride (CPVC) Compounds[6]

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Definitions D 883 and abbreviations with Terminology D 160C unless otherwise indicated.

4. Classification

4.1 Means for selecting and identifying rigid PVC com-

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[1] This specification is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.15 on Thermoplastic Materials.

Current edition approved Oct 15, 1992. Published December 1992. Originally published as D 1784 – 60 T. Last previous edition D 1784 – 90.

[2] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[3] *Annual Book of ASTM Standards*, Vol 08.01.

[4] *Annual Book of ASTM Standards*, Vol 09.01.

[5] *Annual Book of ASTM Standards*, Vol 08.02.

[6] *Annual Book of ASTM Standards*, Vol 08.03.

[7] *Annual Book of ASTM Standards*, Vol 08.04.

Attachment D 1/4

TABLE 1 Class Requirements for Rigid Poly(Vinyl Chloride) Compounds

NOTE—The minimum property value will determine the cell number although the maximum expected value may fall within a higher cell

Designation Order No.	Property and Unit	Cell Limits 0	1	2	3	4	5	6	7	8
1	Base resin	unspecified	poly(vinyl chloride) homopolymer	chlorinated poly(vinyl chloride)	vinyl copolymer					
2	Impact strength (Izod) min:									
	J/m of notch	unspecified	<34.7	34.7	80.1	266.9	533.8	800.7		
	ft·lb/in. of notch		<0.65	0.65	1.5	5.0	10.0	15.0		
3	Tensile strength, min:									
	MPa	unspecified	<34.5	34.5	41.4	48.3	55.2			
	psi		<5 000	5 000	6 000	7 000	8 000			
4	Modulus of elasticity in tension, min:									
	MPa	unspecified	<1930	1930	2206	2482	2758	3034		
	psi		<280 000	280 000	320 000	360 000	400 000	440 000		
5	Deflection temperature under load, min, 1.82 MPa (264 psi):									
	°C	unspecified	<55	55	60	70	80	90	100	110
	°F		<131	131	140	158	176	194	212	230
	Flammability	A	A	A	A	A	A	A	A	A

A All compounds covered by this specification when tested in accordance with Method D 635 shall yield the following results: average extent of burning of <25 mm; average time of burning of <10 s.

pounds are provided in Tables 1 and 2. The properties enumerated in Table 1 and the tests defined are expected to provide identification of the compounds selected. They are not necessarily suitable for direct application in design because of differences in shape of part, size, loading, environmental conditions, etc.

4.2 Classes are designated by the cell number for each property in the order in which they are listed in Table 1 including a suffix letter specifying the requirements for chemical resistance, as shown in Table 2.

NOTE 3—The chemical resistance requirements in Table 2 are included to provide identification of the compounds selected. They are not necessarily suitable for rating of application chemical resistance.

NOTE 4—The manner in which selected materials are identified by this classification system is illustrated by a Class 12454-B rigid PVC compound having the following requirements (see Tables 1 and 2):

Class	1	2	4	5	4	B
Identification:						
Poly(vinyl chloride) homopolymer	1					
Property and Minimum Value:						
Impact strength (Izod) (34.7 J/m (0.65 ft·lbf/in.))		2				
Tensile stength (48.3 MPa (7000 psi))			4			
Modulus of elasticity in tension (2758 MPa (400 000 psi))				5		
Deflection temperature under load (70°C (158°F))					4	
Chemical resistance (meets the requirements of Suffix B in Table 2)						B

NOTE 5—The cell-type format provides the means for identification and close characterization and specification of material properties, alone or in combination, for a broad range of materials. This type format, however, is subject to possible misapplication since unobtainable property combinations can be selected if the user is not familiar with commercially available materials. The manufacturer should be consulted.

4.3 Type and grade number designations have been widely used to define the minimum physical properties and chemical resistance requirements of certain commercial classes of rigid PVC compounds. Table X1.1 in the Appendix lists these type and grade numbers and the corresponding class numbers selected from Table 1 and 2. The classes for previous types and grades of poly(vinyl chloride vinyl acetate) compounds are listed in Table X2.1 in the Appendix.

4.4 Product application chemical resistance when specified shall be classified according to the Classification Section of Classification D 5260.

5. Ordering Information

5.1 The purchase order, or inquiry for these materials shall state the specification number and identify the class selected, for example, D 1784, Class 12454-B.

5.2 Further definition, as may be required for the fol-

TABLE 2 Suffix Designation for Chemical Resistance

Solution	A	B	C	D
H_2SO_4 (93 %)—14 days immersion at 55 ± 2°C:				
Change in weight:				
Increase, max, %	1.0^A	5.0^A	25.0	NA^B
Decrease, max, %	0.1^A	0.1^A	0.1	NA
Change in flexural yield strength:				
Increase, max, %	5.0^A	5.0^A	5.0	NA
Decrease, max, %	5.0^A	25.0^A	50.0	NA
H_2SO_4 (80 %—30 days immersion at 60 ± 2°C:				
Change in weight:				
Increase, max, %	NA	NA	5.0	15.0
Decrease, max, %	NA	NA	5.0	0.1
Change in flexural yield strength:				
Increase, max, %	NA	NA	15.0	25.0
Decrease, max, %	NA	NA	15.0	25.0
ASTM Oil No. 3—30 days immersion at 23°C:				
Change in weight:				
Increase, max, %	0.5	1.0	1.0	10.0
Decrease, max, %	0.5	1.0	1.0	0.1

A Specimens washed in running water and dried by an air blast or other mechanical means shall show no sweating within 2 h after removal from the bath.

B NA = not applicable.

Attachment D 2/4

lowing, shall be on the basis of agreement between the purchaser and the seller.

5.2.1 Physical form and particle size (see 6.1).
5.2.2 Contamination level (see 6.2),
5.2.3 Color (see 6.3),
5.2.4 Other supplementary definition if necessary, and
5.2.5 Inspection (see 12.1).

6. Materials and Manufacture

6.1 Materials supplied under this specification shall be PVC compounds in the form of cubes, granules, free-flowing powder blends, or compacted powder blends.

6.2 Materials shall be of uniform composition and size and shall be free of foreign matter to such level of contamination as may be agreed between the purchaser and the seller.

6.3 Color and transparency or opacity of molded or extruded articles formed under the conditions recommended by the seller shall be comparable within commercial match tolerances to the color and transparency or opacity of standard molded or extruded samples of the same thickness supplied in advance by the seller of the material.

7. Physical Requirements

7.1 Test values for specimens of the material prepared as specified in Section 9 and tested in accordance with Section 10 shall conform to the requirements given in Tables 1 and 2 for the class selected.

. Sampling

8.1 A batch or lot shall be considered as a unit of manufacture and may consist of a blend of two or more production runs of material.

8.2 Unless otherwise agreed upon between the seller and the purchaser, the material shall be sampled in accordance with the procedure described in the General and Specific Sampling Procedures, as applicable, of Practice D 1898. Adequate statistical sampling prior to packaging shall be considered an acceptable alternative.

9. Testing

9.1 The requirements identified by the class designation and otherwise specified in the purchase order (see 5.1) shall be verified by tests made in accordance with the directions given in Section 11. For routine inspection, only those tests necessary to identify the materials to the satisfaction of the purchaser shall be required. One sample shall be sufficient for testing each batch or lot provided that the average values for all of the tests made on that batch or lot comply with the specified requirements.

9.2 If any failure occurs, the materials may be retested in accordance with agreement between the purchaser and the seller (see 12.1).

10. Specimen Preparation

10.1 Compliance with the designated requirements chosen from Tables 1 and 2 shall be determined with compression-molded test specimens. Procedures used in preparing the test specimens shall be as recommended by the seller. The procedures shall be the same for all test specimens required by Section 11. Test specimens shall conform to the requirements prescribed in Section 11.

10.2 Subject to agreement between the purchaser and seller, tests may be made on specimens prepared from finished molded or extruded articles. Results of such tests may not agree with the values given by specimens prepared in accordance with 10.1. Therefore, in reports of such tests, methods and conditions of preparation, dimensions, and all other pertinent information shall be included. Compression molding shall be the referee method.

11. Test Methods

11.1 *Conditioning*—The test specimen for deflection temperature (Test Method D 648) shall be conditioned in accordance with Procedure B of Methods D 618, except that the minimum conditioning time in the circulating air oven shall be 24 h. All other molded test specimens shall be conditioned in accordance with Procedure A of Methods D 618. The minimum conditioning time shall be 24 h.

11.2 *Test Conditions*—Unless otherwise specified in the testing methods or in this specification, tests shall be conducted in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 % relative humidity.

11.3 *Tensile Strength and Modulus of Elasticity*—Test Method D 638, using Type I specimens.

NOTE 6—Current industrial practice uses a specimen thickness of 3.2 ± 0.4 mm (0.13 ± 0.02 in.) and a speed of testing of 5.1 mm (0.20 in.)/min ± 25 %.

11.4 *Flexural Yield Strength*—Procedure B of Test Methods D 790 using 12.5 by 3.2 mm (½ by ⅛ in.) specimens, 2 in. span at 1.3 mm/min (0.05 in./min).

11.5 *Impact Strength (Izod)*—Method A of Test Methods D 256, using 6.35-mm (0.25-in.) thick specimens. The specimens may be compression- or injection-molded with the provision that compression-molded specimens built up as laminates in which complete fusion is obtained shall be acceptable. Complete fusion means there shall be no evidence of fraying or delamination at the break.

11.6 *Deflection Temperature*—Test Method D 648 using 12.5 by 3.2 mm (½ by ⅛ in.) specimens under 1.82 MPa (264 psi) load.

11.7 *Flammability*—Test Method D 635.

11.8 *Chemical Resistance*—Test Method D 543, using the test specimen 25.4 by 76.2 by 3.2 mm (1 by 3 by ⅛ in.) and the test conditions and reagents specified in Table 2 as follows:

11.8.1 *Sulfuric Acid (93.0 %)*—The acid shall be 66° Baumé (92.98 to 93.41 % sulfuric acid (H_2SO_4) sp gr 1.8364 to 1.8344 at 60/60°F). The specimen must be completely immersed in the acid.

11.8.2 *Sulfuric Acid (80 %)*—The concentration of 80 % H_2SO_4 is not critical but must be held to an 80 ± 2 % level to meet the requirements of this specification. The samples must be immersed completely. Glass or acid-resistant wire may be used for sinkers.

11.8.3 *Adjustment of Acid Strength*—The H_2SO_4 content of the acid solutions may be determined by titration with sodium hydroxide (NaOH) solution and methyl orange indicator or by specific gravity with hydrometers sensitive and accurate to 0.001. The H_2SO_4 content should be adjusted to the required strength by mixing dilute and concentrated acids.

11.8.4 *ASTM Oil No. 3*—ASTM Oil No. 3 shall meet the requirements prescribed in Test Method D 471.

11.9 *Particle Size* (*Sieve Analysis of Plastic Materials*)—Test Methods D 1921.

12. Inspection

12.1 Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchase contract.

13. Packaging and Package Marking

13.1 *Packaging*—The material shall be packaged in standard commercial containers, so constructed as to ensure acceptance by common or other carriers for safe transportation at the lowest rate to the point of delivery, unless otherwise specified in the contract or order.

13.2 *Marking*—Unless otherwise agreed upon between the purchaser and seller, shipping containers shall be marked with the name of the material, and the name of the manufacturer, class, batch or lot number, quantity contained therein, as defined by the contract or order under which shipment is made, the name of the seller, and the number of the contract or order.

13.3 All packing, packaging, and marking provisions of Practice D 3892 shall apply to this specification.

14. Keywords

14.1 chlorinated poly(vinyl chloride) (CPVC); CPVC compounds; poly(vinyl chloride) (PVC); PVC compounds; rigid PVC

APPENDIXES

(Nonmandatory Information)

X1. CLASSIFICATION OF COMMERCIAL TYPES AND GRADES OF RIGID POLY(VINYL CHLORIDE) COMPOUNDS

TABLE X1.1 Comparison of Former and New Designations

Former Commercial Type and Grade from Former Specification D 1784 – 65 T	Class from Table 1
Type I, Grade 1	12454-B
Type I, Grade 2	12454-C
Type I, Grade 3	11443-B
Type II, Grade 1	14333-D
Type III, Grade 1	13233
Type IV, Grade 1	23447-B
Type V, Grade 1	15223-B

X2. CLASSIFICATION OF COMMERCIAL TYPES AND GRADES OF RIGID VINYL CHLORIDE COPOLYMERS

TABLE X2.1 Comparison of Former and New Designations

Former Commercial Type and Grade from Former Specification D 2114 – 66	Class from Table 1
Type I, Grade 1	51332
Type I, Grade 2	51331
Type II, Grade 1	52222
Type II, Grade 2	53212
Type II, Grade 3	55212

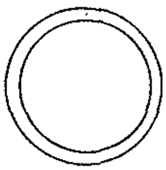
Attachment D 4

Written by: ____________ Date: __/__/__ (YY MM DD) Reviewed by: ____________ Date: __/__/__ (YY MM DD)

Client: ____________ Project: ____________ Project/Proposal No.: ____________ Task No.: ____________

MOMENT OF INERTIA, I

PVC PIPE: OUTSIDE DIA: D = 2.375" ⟹ R = 1.1875"
INSIDE DIA: D = 2.067" R = 1.0335"



$I = I_{OUT} - I_{in}$ $I_{CIRCLE} = \frac{\pi R^4}{4}$

$$I = \frac{\pi (1.1875)^4}{4} - \frac{\pi (1.0335)^4}{4}$$

$$I = 1.5618 - 0.896$$

$$I = 0.666 \text{ in}^4$$

ATTACHMENT E 1/1

Written by: Steve Fitzwilliam Date: 06/3/15 (YY MM DD) Reviewed by: Greg Corcoran Date: ___/___/___ (YY MM DD)

Client: Slough Estates USA Inc Project: Britannia East Grand Ph II Project/Proposal No.: SC0347 Task No.: 01

GEOTEXTILE PUNCTURE PROTECTION OF LIQUID BOOT BUILDING 2

OBJECTIVE

At the proposed Britannia East Grand development site in South San Francisco, California, an 80-mil (2.0-mm) Liquid Boot cold spray applied geomembrane gas barrier will be subjected to forces, such as foot traffic, steel reinforcement and poured concrete that may damage the Liquid Boot geomembrane. The Liquid Boot geomembrane will be spray applied to a heat bonded nonwoven carrier geotextile, which will serve to protect the geomembrane from puncture. In addition, a nonwoven needle-punched cushion geotextile will be installed over the geomembrane gas barrier to protect the geomembrane gas barrier from damage during installation of the overlying reinforcement and concrete slab. The objective of this calculation is to evaluate the required puncture strength of both the heat bonded nonwoven carrier geotextile and the nonwoven, needle-punched cushion geotextile.

SUMMARY OF ANALYSIS

The analysis suggests that the puncture strength of the heat bonded nonwoven carrier geotextile be greater than **41** lbs. for Linq 3401. The analysis also suggests that the puncture strength of the nonwoven needle-punched cushion geotextile be greater than **78.0** lbs. for 10 oz/yd^2. A summary of required geotextile properties and a list of geotextile products that meet the material requirements are provided at the end of this calculation package.

SITE CONDITIONS

The components beneath the building are the following, from top to bottom:

- 10 inches of concrete;
- protection course (a nonwoven needle-punched cushion geotextile);
- 80 mil Liquid Boot geomembrane for calculation (minimum thickness recommended 100-mil)
- heat bonded nonwoven carrier geotextile; and

A cross-section of the gas extraction system is presented as Attachment A.

ANALYSIS

- **OVERLYING PRESSURE**:

The gas barrier system will be overlain by a nonwoven needle-punched cushion geotextile and a 10 inch concrete floor slab. The maximum loading will be no greater than the loads associated with the construction of the concrete structural slab. The construction loads include foot traffic, steel reinforcement and associated support, and the load of the concrete. This pressure will be exerted directly on the geotextile/geomembrane.

1. Assuming the unit weight of the concrete is 150 pcf, the pressure on the geomembrane due to concrete is assumed to be:

   (150 pcf)(0.833 ft) = 125 psf = 0.868 psi

2. Steel reinforcement loads are assumed to be a combination of the top and bottom reinforcement, both spaced 10" on center. It is assumed that the reinforcement is supported by a 2"x2" masonry support, spaced every 5 ft. Reinforcement will be #4 steel bars, with a nominal diameter of 0.500 in. and a nominal weight of 0.668 lbs./ft. (Attachment B).

   To calculate the weight of reinforcement per square foot in the top rebar, the amount of steel is determined. Four feet of reinforcement is used per square foot, and half of the weight for each bar is attributed per square foot of pressure.

   Top: for 1 sq. ft., pressure = 4 ft.* 0.668 lbs./ft = 2.672 lbs.
   for 5 sq. ft., pressure = 5^2 * 4 ft. * 0.668 lbs./ft = 66.8 lbs.
   = 66.8 lbs./ (2 in.* 2 in.) = 16.7 psi

   To calculate the weight of reinforcement per square foot in the bottom rebar, the amount of steel is determined. Two feet of reinforcement is used per square foot.

   Bottom: for 1 sq. ft., pressure = 2 ft * 0.668 lbs./ft = 1.336 lbs.
   For 5 sq. ft., pressure = 5^2 * 2 ft. * 0.668 lbs./ft = 33.4 lbs.
   = 33.4 lbs./(2 in.* 2in.) = 8.35 psi

   Total Steel Rebar Pressure = 16.7 + 8.35 = 25.1 **psi**

Based on the above calculations, the combined pressure resulting from the concrete and rebar dead weight will be used to design the required cushion geotextiles. The combined pressure is:

(0.868 psi) + (25.1 psi) = 26.0 **psi**

APPROACH

- **CUSHION GEOTEXTILE**

The cushion geotextile will serve to protect the Liquid Boot geomembrane from puncture by the 2"x2" masonry blocks.

Koerner has developed the following method for evaluating the puncture resistance of a geotextile:

$F_{vert} = [(\pi d_h)(h_h)p']S'$ (Attachment C)

where
- F_{vert} = the total vertical force imposed on the fibers,
- d_h = the average diameter of the hole
- h_h = the propagation height
- p' = the pressure exerted on the geotextile,
- S' = the shape factor, varying from 0 for blunt objects to 1.0 for sharp objects

EVALUATE EQUATION

d_h = 2 in (from the 2"x 2" masonry blocks)

h_h = 2 in. (from the 2"x 2" masonry blocks)

p' = 26.0 psi

S' = 0.1 (masonry block is relatively blunt)

Plugging in variables,

$$F_{vert} = [(\pi d_h)(h_h)p']S'$$
$$= [(\pi * 2\text{ in.})(2\text{ in.})(26.0\text{ psi})](0.1)$$
$$= 32.6\text{ lbs.}$$

Koerner suggests applying partial factor of safety values to the ultimate puncture strength of the geotextile to account for installation damage, creep, and chemical and biological degradation (Attachment C). Therefore, the following values for geotextiles used in separation, as suggested by Koerner, will be used:

- Installation Damage 2.0
- Creep 1.2
- Chemical Degradation 1.0
- Biological Degradation 1.0

Therefore, the allowable puncture strength of the geotextile (F_{alow}) as measured by ASTM D4833 is:

F_{allow} = 32.6 lbs.(2.0)(1.2)(1.0)(1.0) = 78.17 lbs. ≈ **78.0 lbs.**

- **CARRIER GEOTEXTILE**

The geotextile typically used in this application is Typar type heat bonded nonwoven geotextiles distributed by Linq Industries. Based on Linq geotextile specifications (Attachment D), Typar 3401 will provide a puncture resistance of 41 lbs.

The puncture resistance needed for the carrier geotextile is negligible due to the combined mass per unit area of 12 oz/yd^2 for the two geotextile components of the geocomposite, which is acceptable based on the above calculations for a 2" square blunt object. Since the geocomposite and carrier geotextile will overlie native soil, a maximum particle size will be determined as follows:

Puncture strength of geotextiles = carrier geotextile strength

Puncture strength = **41 lbs.**

Dividing by Koerner's factors of safety described above,
Puncture strength = 41 lbs./[(2.0)(1.2)(1.0)(1.0)]
= 17.1 lbs.

Using Koerner's method for evaluating puncture resistance described above,

$F_{vert} = [(\pi)(d^2)p']S'$ (Attachment C)

where F_{vert} = the total vertical force imposed on the fibers,
d = the average diameter of the particle
p' = the pressure exerted on the geotextile,
S' = the shape factor

EVALUATE EQUATION

F_{vert} = 17.1 lbs.

p' = 32.6 psi

S' = 0.75 (assumed for particles in soil)

Plugging in variables,

$F_{vert} = [(\pi)(d^2)p']S'$
$17.1 = [(\pi)(d^2)(32.6 \text{ psi})](0.75)$
$d^2 = 0.22$
$d = 0.47$ in

Therefore, the maximum particle size should be limited to, $\mathbf{d_{max}}$ **= 7/16"**

CONCLUSIONS

Assuming the following:

- the construction loads do not exceed 32.6 psi; and
- the rebar supports are 2"x 2" masonry blocks, spaced 5 ft. on center.

A heat bonded nonwoven carrier geotextile with a puncture strength greater than 41 lbs. will be adequate for protection of the Liquid Boot geomembrane. A nonwoven needle-punched cushion geotextile with a puncture strength greater than 78.0 lbs. will be adequate for protection of the Liquid Boot geomembrane.

• COMPLETE SET OF GEOTEXTILE PROPERTIES

Typical Typar 3401 heat bonded nonwoven carrier geotextile, when subjected to laboratory testing, should provide the following mechanical property values:

Property	Value
puncture strength	> 41 lb.
grab strength	> 130 lb.
burst strength	> 140 psi
trapezoidal tear	> 60 lb.
ultraviolet strength retention	> 70 %

Typical nonwoven needle-punched 10 oz/yd^2 cushion geotextile, when subjected to laboratory testing, should provide the following mechanical property values:

Property	Value
puncture strength	> 78.0 lb.
grab strength	> 250 lb.
burst strength	> 460 psi
trapezoidal tear	> 100 lb.
ultraviolet strength retention	> 70 %

• GEOTEXTILE PRODUCTS THAT MEET REQUIREMENTS

The following is a partial list of geotextile products that meet the property values stated above for carrier geotextile:

- Linq Typar 3401

The following is a partial list of geotextile products that meet the property values stated above for cushion geotextile:

- Amoco 4510
- Linq 275EX
- Synthetic Industries Geotex 1001
- TC Mirafi 1100N

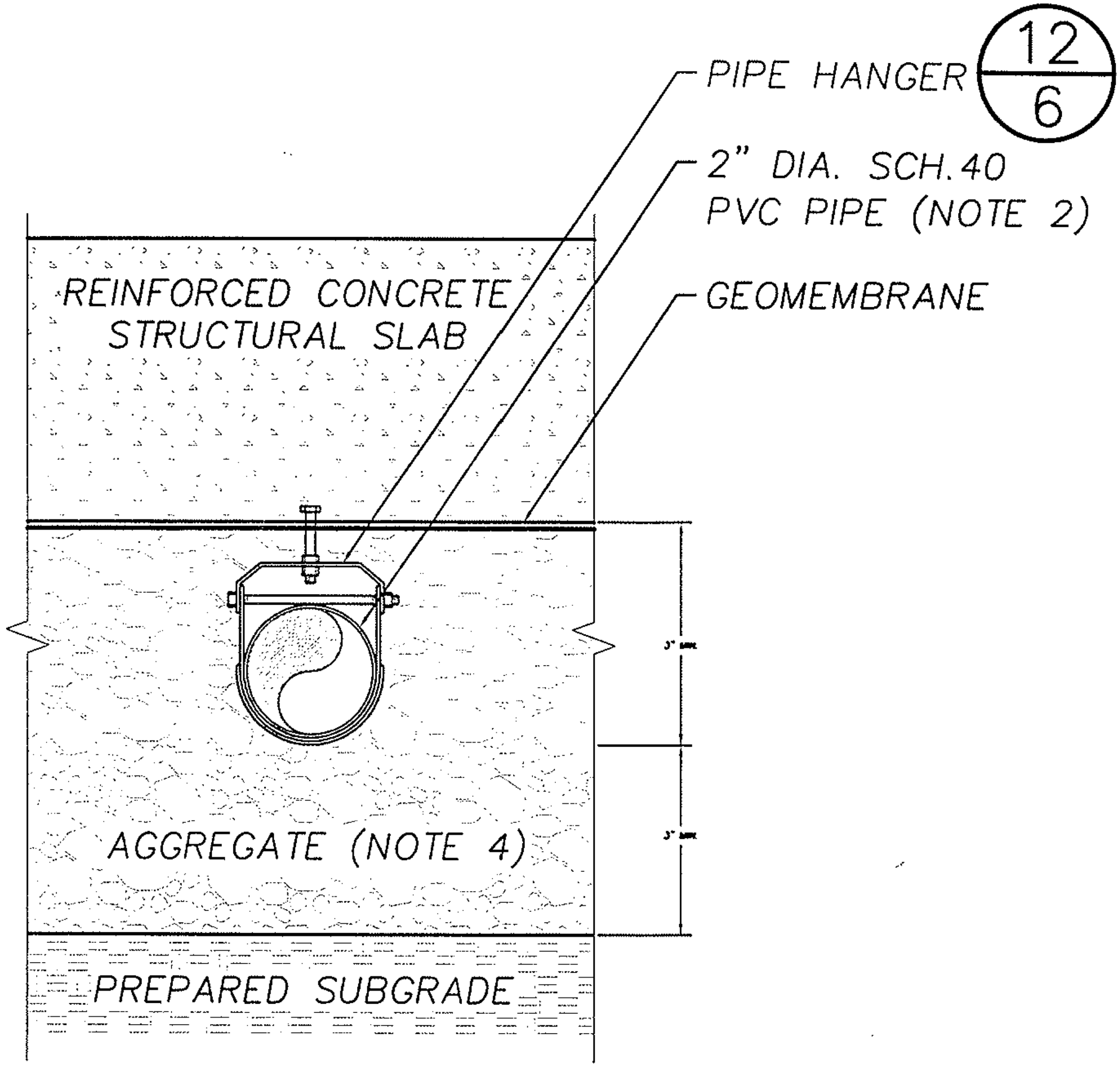
Written by: Steve Fitzwilliam Date: 06/3/15 (YY MM DD) Reviewed by: Greg Corcoran Date: ___/___/___ (YY MM DD)

Client: Slough Estates USA Inc Project: Britannia East Grand Ph II Project/Proposal No.: SC0347 Task No.: 01

REFERENCES

ACI 318-95 and ACI 318-95R "Building Code Requirements for Structural Concrete and Commentary," American Concrete Institute, Farmington Hills, MI, USA

Koerner, R.M. (1990) "Designing with Geosynthetics", 2nd Edition, Prentice Hill, New Jersey.



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SECTION
GAS EXTRACTION SYSTEM
N.T.S.

ATTACHMENT A, 1/1

APPENDIX E — STEEL REINFORCEMENT INFORMATION

As an aid to users of the ACI Building Code, information on sizes, areas, and weights of various steel reinforcement is presented.

ASTM STANDARD REINFORCING BARS

Bar size, no.	Nominal diameter, in.	Nominal area, in.^{2}	Nominal weight, lb/ft
3	0.375	0.11	0.376
4	0.500	0.20	0.668
5	0.625	0.31	1.043
6	0.750	0.44	1.502
7	0.875	0.60	2.044
8	1.000	0.79	2.670
9	1.128	1.00	3.400
10	1.270	1.27	4.303
11	1.410	1.56	5.313
14	1.693	2.25	7.650
18	2.257	4.00	13.600

ASTM STANDARD PRESTRESSING TENDONS

Type*	Nominal diameter, in.	Nominal area, in.^{2}	Nominal weight, lb/ft
Seven-wire strand (Grade 250)	1/4 (0.250)	0.036	0.122
	5/16 (0.313)	0.058	0.197
	3/8 (0.375)	0.080	0.272
	7/16 (0.438)	0.108	0.367
	1/2 (0.500)	0.144	0.490
	(0.600)	0.216	0.737
Seven-wire strand (Grade 270)	3/8 (0.375)	0.085	0.290
	7/16 (0.438)	0.115	0.390
	1/2 (0.500)	0.153	0.520
	(0.600)	0.217	0.740
Prestressing wire	0.192	0.029	0.098
	0.196	0.030	0.100
	0.250	0.049	0.170
	0.276	0.060	0.200
Prestressing bars (plain)	3/4	0.44	1.50
	7/8	0.60	2.04
	1	0.78	2.67
	1-1/8	0.99	3.38
	1-1/4	1.23	4.17
	1-3/8	1.48	5.05
Prestressing bars (deformed)	5/8	0.28	0.98
	3/4	0.42	1.49
	1	0.85	3.01
	1-1/4	1.25	4.39
	1-3/8	1.58	5.56

* Availability of some tendon sizes should be investigated in advance.

Attachment B 1/1

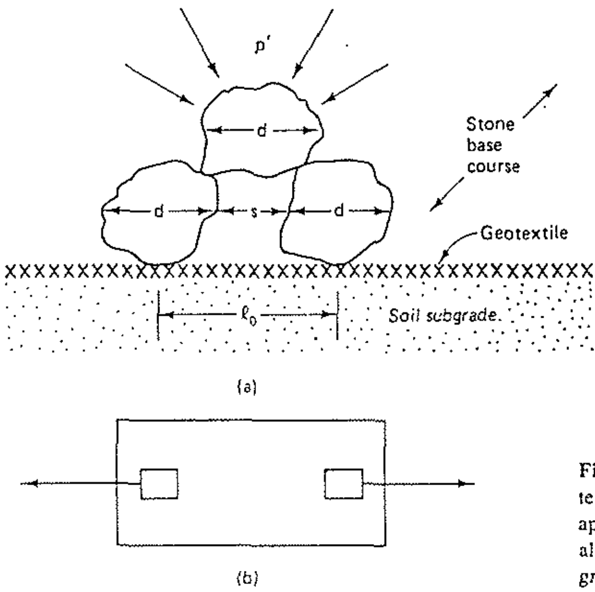

Figure 2.26 Geotextile being subjected to tensile (Grab) stress as surface pressure is applied and stone base tends to spread laterally. (a) Actual situation. (b) Analogous grab tension test.

2.5.4 Puncture (Tear) Resistance

Although not only related to the separation function, the geotextile during its placement must survive the installation process. Indeed, fabric survivability is critical in all types of applications; without it, the best of designs are futile (recall Section 2.2.6.1). In this regard, sharp stones, tree stumps, roots, miscellaneous debris, and other things on the ground beneath the geotextile could puncture through the fabric after stone base and traffic loads are imposed above it. The design method suggested for this situation is shown schematically in Figure 2.27. For these conditions, the vertical force exerted on the geotextile (which is gradually tightening around the object) is as follows:

$$F_{vert} = [(\pi d_h)(h_h)\, q']S' \qquad (2.26)$$

where

- F_{vert} = the total vertical force imposed on the fibers adjacent to the puncture;
- d_h = the average diameter of the hole, where d_h (maximum) = d_a = average diameter of the aggregate (or stump, etc.);
- h_h = the propagation height ($\approx d_a$);
- p' = the pressure exerted on the geotextile (usually 75% to 100% of tire inflation pressure at the ground surface); and
- S' = the shape factor varying from 0 for rounded blunt objects to 1.0 for sharp angular objects (for aggregate particles, the shape factor can be assumed to be $(1.0 - S)$, where S is the sphericity, from $S = A_p/A_c$, where A_p is the

Attachment C 1/3

projected area of the particle and A_c is the area of the smallest circumscribing circle around the particle; typical values of S are 0.8 for Ottawa sand, 0.7 for run-of-bank gravel, 0.4 for crushed rock, and 0.3 for shot rock).

This vertical force must now be converted into a tensile force in the fibers of the geotextile. This is indeed a complex problem, since both radial friction and axial rotation of the fibers against the protrusion are involved. As an approximation, however, we can use

$$\frac{F_{\text{vert}}}{T_{\text{reqd}}} = \frac{d_a}{d_i} \tag{2.27}$$

where

F_{vert} = the total vertical force on fibers,
T_{reqd} = the required tensile force in fibers,
d_a = the average diameter of the stone, and
d_i = the initial average void diameter of geotextile.

Combining equations, with the assumptions noted above, one obtains

$$T_{\text{reqd}}\left(\frac{d_a}{d_i}\right) = (\pi d_a^2 p')S'$$

$$T_{\text{reqd}} = (\pi d_i d_a)\, p'S' \tag{2.28}$$

This value of T_{reqd} can be compared to the puncture test (if the object is blunt, causing puncture) or to the tear test (if the object is sharp, causing tear). Both types of tests were described in Section 2.2.3.

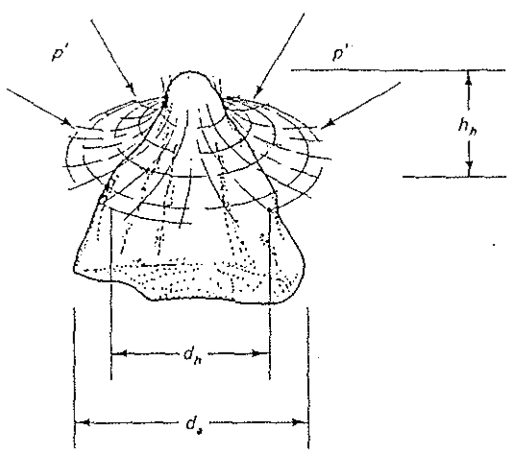

Figure 2.27 Visualization of a stone puncturing a geotextile as pressure is applied from above.

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Attachment C 2/3

TABLE 2.12 RECOMMENDED PARTIAL FACTOR OF SAFETY VALUES FOR USE IN EQUATION 2.18

Application area	Various partial factors of safety: Installation damage	Creep*	Chemical degradation	Biological degradation
separation	1.1 to 2.5	1.0 to 1.2	1.0 to 1.5	1.0 to 1.2
cushioning	1.1 to 2.0	1.2 to 1.5	1.0 to 2.0	1.0 to 1.2
unpaved roads	1.1 to 2.0	1.5 to 2.5	1.0 to 1.5	1.0 to 1.2
walls	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5	1.0 to 1.3
embankments	1.1 to 2.0	2.0 to 3.0	1.0 to 1.5	1.0 to 1.3
bearing capacity	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5	1.0 to 1.3
slope stabilization	1.1 to 1.5	1.5 to 2.0	1.0 to 1.5	1.0 to 1.3
pavement overlays	1.1 to 1.5	1.0 to 1.2	1.0 to 1.5	1.0 to 1.1
railroads	1.5 to 3.0	1.0 to 1.5	1.5 to 2.0	1.0 to 1.2
flexible forms	1.1 to 1.5	1.5 to 3.0	1.0 to 1.5	1.0 to 1.1
silt fences	1.1 to 1.5	1.5 to 2.5	1.0 to 1.5	1.0 to 1.1

*The low end of the range refers to results that have been compensated for creep in the performance of the tests.

$$T_{\text{allow}} = T_{\text{ult}} \left(\frac{1}{FS_{ID} \times FS_{CR} \times FS_{CD} \times FS_{BD}} \right) \tag{2.18}$$

where

T_{allow} = the allowable tensile strength,
T_{ult} = the ultimate tensile strength,
FS_{ID} = the factor of safety for installation damage,
FS_{CR} = the factor of safety for creep,
FS_{CD} = the factor of safety for chemical degradation, and
FS_{BD} = the factor of safety for biological degradation. (close to 1)

Note that this equation could just as well have been formulated as fractional multipliers (≤ 1.0) and placed in the numerator of the equation. It is placed in this form because other studies have done likewise (e.g., Voskamp and Risseeuw [37]). While the equation indicates tensile strength, it can equally well be applied to burst strength, tear strength, puncture strength, seam strength, etc.

For problems dealing with flow through or within a geotextile, the formulation takes the following form with typical values given in Table 2.13. Note that these values must be tempered with site-specific conditions as was the case with the previous table.

$$q_{\text{allow}} = q_{\text{ult}} \left(\frac{1}{FS_{SCB} \times FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC}} \right) \tag{2.19}$$

Attachment C 3/3

GEOTEXTILES

LINQ Industrial Fabrics Inc.

Product Name (Structure [1]/ Polymer Type [2])	Mass Per Unit Area ASTM D 5261 g/m² (oz/yd²)	H288 Transportation-Related Applications: Filtration/Hydraulic Properties: Percent Open Area CWO-22125 %	Apparent Opening Size ASTM D 4751 mm (U.S. sieve)	Permittivity ASTM D 4491 sec⁻¹ Flow Rate (FH or CH) [3] l/min/m² (gal/min/ft²)	Physical Properties: Puncture ASTM D 4833 kN (lb)	Trapezoid Tearing Strength ASTM D 4533 kN (lb)	Grab Tensile/ Elongation ASTM D 4632 kN (lb)/%	H288 Survivability Class	H288 Applications [4]	Reinforcement Applications: Wide Width Tensile Properties ASTM D 4595 kN/m (lb/in.): Strength @ 5% Strain [5] MD	Strength @ 5% Strain [5] XD	Ultimate Strength % (T_{ult}) [5] MD	Ultimate Strength % (T_{ult}) [5] XD	Creep Limited Strength ASTM D 5262 [7] kN/m (lb/ft)	T_{allow} GRI GT7 (in sand) [6]	Other Manufacturer's Suggested Applications [8]
Typar 3341 (NW-PP)	NP	NP	0.25 (60)	0.70, FH	0.134 (30)	0.178 (40)	0.534 (120)/60	—	—	NP	NP	NP	NP	NP	NP	F, D
Typar 3401 (NW-PP)	NP	NP	0.21 (70)	0.70, FH	0.180 (41)	0.267 (60)	0.579 (130)/60	3	SP, ST, D	NP	NP	NP	NP	NP	NP	S/S, F, D
Typar 3501 (NW-PP)	NP	NP	0.21 (70)	0.70, FH	0.250 (56)	0.265 (60)	0.710 (160)/60	2	SP, ST, D	NP	NP	NP	NP	NP	NP	S/S, F, D
Typar 3631 (NW-PP)	NP	NP	0.106 (140)	0.20, FH	0.355 (80)	0.401 (90)	1.113 (250)/60	1	ST, E	NP	NP	NP	NP	NP	NP	S/S, F, D
125EX (NW-PP)	NP	NP	0.21 (70)	1.6, FH	0.244 (55)	0.178 (40)	0.401 (90)/50	—	—	NP	NP	NP	NP	NP	NP	A/O, F, D
130EX (NW-PP)	NP	NP	0.21 (70)	1.4, FH	0.267 (60)	0.200 (45)	0.467 (105)/50	—	—	NP	NP	NP	NP	NP	NP	A/O, F, D
140EX (NW-PP)	NP	NP	0.21 (70)	1.1, FH	0.289 (65)	0.222 (50)	0.534 (120)/50	3	SP, ST D, A/O	NP	NP	NP	NP	NP	NP	S/S, F, D
150EX (NW-PP)	NP	NP	0.18 (80)	1.1, FH	0.401 (90)	0.289 (65)	0.734 (165)/50	2	ST, ST, D	NP	NP	NP	NP	NP	NP	S/S, F, D
160EX (NW-PP)	NP	NP	0.18 (80)	1.1, FH	0.401 (90)	0.312 (70)	0.801 (180)/50	—	—	NP	NP	NP	NP	NP	NP	S/S, F, D

[1] NW = Nonwoven, -P = needlepunched, -h = calendered
W = Woven, -SF = slit film
K = Knitted O/C = Other/combination
[2] PP = Polypropylene PET = Polyester
[3] FH = Test is run by the falling head method
CH = Test is run by the constant head method
[4] SP = Separation S/F = Silt Fence
ST = Stabilization D = Drainage
F = Filtration E = Erosion Control
A/O = Asphalt overlay
[5] MD = Machine direction XD = Cross-machine direction
[6] $T_{allow} = \frac{T_{ult}}{RF_{CR} \times RF_{ID} \times RF_D}$
RF_{CR} = Reduction factor for creep
RF_{ID} = Reduction factor for installation damage
RF_D = Reduction factor for durability

NOTE: This equation does not include other reduction factors which may apply to design. Reduction factors are site specific and should be reviewed on a per project basis. Contact the manufacturer for recommendations.
[7] For a minimum of 10,000 hours, extrapolated to a 75-year time period
[8] R = Reinforcement P = Protection
RC = Reinforcement Composite

SP = Separation S/F = Silt Fence
ST = Stabilization D = Drainage
F = Filtration E = Erosion Control
A/O = Asphalt overlay
NP = Not provided by manufacturer
NA = Not applicable per manufacturer

Attachment D

Written by: Steve Fitzwilliam Date: 06/3/15 (YY MM DD) Reviewed by: Greg Corcoran Date: / / (YY MM DD)

Client: Slough Estates USA Inc Project: Britannia East Grand Ph II Project/Proposal No.: SC0347 Task No.: 01

GEOTEXTILE PUNCTURE PROTECTION OF LIQUID BOOT PARKING STRUCTURE B

OBJECTIVE

At the proposed Britannia East Grand development site in South San Francisco, California, an 80-mil (2.0-mm) Liquid Boot cold spray applied geomembrane gas barrier will be subjected to forces, such as foot traffic, steel reinforcement and poured concrete that may damage the Liquid Boot geomembrane. The Liquid Boot geomembrane will be spray applied to a heat bonded nonwoven carrier geotextile, which will serve to protect the geomembrane from puncture. In addition, a nonwoven needle-punched cushion geotextile will be installed over the geomembrane gas barrier to protect the geomembrane gas barrier from damage during installation of the overlying reinforcement and concrete slab. The objective of this calculation is to evaluate the required puncture strength of both the heat bonded nonwoven carrier geotextile and the nonwoven, needle-punched cushion geotextile.

SUMMARY OF ANALYSIS

The analysis suggests that the puncture strength of the heat bonded nonwoven carrier geotextile be greater than **41** lbs. for Linq 3401. The analysis also suggests that the puncture strength of the nonwoven needle-punched cushion geotextile be greater than **116** lbs. for 10 oz/yd^2. A summary of required geotextile properties and a list of geotextile products that meet the material requirements are provided at the end of this calculation package.

SITE CONDITIONS

The components beneath the building are the following, from top to bottom:

- 10 inches of concrete;
- protection course (a nonwoven needle-punched cushion geotextile);
- 80 mil Liquid Boot geomembrane for calculation (minimum thickness recommended 100-mil)
- heat bonded nonwoven carrier geotextile; and

A cross-section of the gas extraction system is presented as Attachment A.

Written by: Steve Fitzwilliam Date: 06/3/15 (YY MM DD) Reviewed by: Greg Corcoran Date: __/__/__ (YY MM DD)

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ANALYSIS

- **OVERLYING PRESSURE**:

The gas barrier system will be overlain by a nonwoven needle-punched cushion geotextile and a 10 inch concrete floor slab. The maximum loading will be no greater than the loads associated with the construction of the concrete structural slab. The construction loads include foot traffic, steel reinforcement and associated support, and the load of the concrete. This pressure will be exerted directly on the geotextile/geomembrane.

1. Assuming the unit weight of the concrete is 150 pcf, the pressure on the geomembrane due to concrete is assumed to be:

   (150 pcf)(0.833 ft) = 125 psf = 0.868 psi

2. Steel reinforcement loads are assumed to be a combination of the top and bottom reinforcement, both spaced 12" on center. It is assumed that the reinforcement is supported by a 2"x2" masonry support, spaced every 5 ft. Reinforcement will be #6 steel bars, with a nominal diameter of 0.750 in. and a nominal weight of 1.502 lbs./ft. (Attachment B).

   To calculate the weight of reinforcement per square foot in the top rebar, the amount of steel is determined. Four feet of reinforcement is used per square foot, and half of the weight for each bar is attributed per square foot of pressure.

   Top: for 1 sq. ft., pressure = 1/2*(4 ft.* 1.502 lbs./ft) = 3.004 lbs.
   for 5 sq. ft., pressure = 5^2*1/2*(4 ft. * 1.502 lbs./ft) = 75.100 lbs.
   = 75.100 lbs./ (2 in.* 2 in.) = 18.8 psi

   To calculate the weight of reinforcement per square foot in the bottom rebar, the amount of steel is determined. Two feet of reinforcement is used per square foot.

   Bottom: for 1 sq. ft., pressure = 2 ft * 1.502 lbs./ft = 3.004 lbs.
   For 5 sq. ft., pressure = 5^2 * 2 ft. * 1.502 lbs./ft = 75.100 lbs.
   = 75.100 lbs./(2 in.* 2in.) = 18.8 psi

   Total Steel Rebar Pressure = 18.8 + 18.8 = 37.6 **psi**

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Based on the above calculations, the combined pressure resulting from the concrete and rebar dead weight will be used to design the required cushion geotextiles. The combined pressure is:

(0.868 psi) + (37.6 psi) = **38.5 psi**

APPROACH

- **CUSHION GEOTEXTILE**

The cushion geotextile will serve to protect the Liquid Boot geomembrane from puncture by the 2"x2" masonry blocks.

Koerner has developed the following method for evaluating the puncture resistance of a geotextile:

$F_{vert} = [(\pi d_h)(h_h)p']S'$ (Attachment C)

where F_{vert} = the total vertical force imposed on the fibers,
d_h = the average diameter of the hole
h_h = the propagation height
p' = the pressure exerted on the geotextile,
S' = the shape factor, varying from 0 for blunt objects to 1.0 for sharp objects

EVALUATE EQUATION

d_h = 2 in (from the 2"x 2" masonry blocks)

h_h = 2 in. (from the 2"x 2" masonry blocks)

p' = 38.5 psi

S' = 0.1 (masonry block is relatively blunt)

Plugging in variables,

F_{vert} $= [(\pi d_h)(h_h)p']S'$
$= [(\pi * 2 \text{ in.})(2 \text{ in.})(38.5 \text{ psi})](0.1)$
= 48.34 lbs.

Koerner suggests applying partial factor of safety values to the ultimate puncture strength of the geotextile to account for installation damage, creep, and chemical and biological degradation (Attachment C). Therefore, the following values for geotextiles used in separation, as suggested by Koerner, will be used:

- Installation Damage 2.0
- Creep 1.2
- Chemical Degradation 1.0
- Biological Degradation 1.0

Therefore, the allowable puncture strength of the geotextile (F_{alow}) as measured by ASTM D4833 is:

F_{allow} = 48.34 lbs.(2.0)(1.2)(1.0)(1.0) = 116.016 lbs. ≈ **116 lbs.**

- **CARRIER GEOTEXTILE**

The geotextile typically used in this application is Typar type heat bonded nonwoven geotextiles distributed by Linq Industries. Based on Linq geotextile specifications (Attachment D), Typar 3401 will provide a puncture resistance of 41 lbs.

The puncture resistance needed for the carrier geotextile is negligible due to the combined mass per unit area of 12 oz/yd^2 for the two geotextile components of the geocomposite, which is acceptable based on the above calculations for a 2" square blunt object. Since the geocomposite and carrier geotextile will overlie native soil, a maximum particle size will be determined as follows:

Puncture strength of geotextiles = carrier geotextile strength

Puncture strength = **41 lbs.**

Dividing by Koerner's factors of safety described above,
Puncture strength = 41 lbs./[(2.0)(1.2)(1.0)(1.0)]
= 17.1 lbs.

Using Koerner's method for evaluating puncture resistance described above,
$F_{vert} = [(\pi)(d^2)p']S'$ (Attachment C)

where F_{vert} = the total vertical force imposed on the fibers,
d = the average diameter of the particle
p' = the pressure exerted on the geotextile,
S' = the shape factor

EVALUATE EQUATION

F_{vert} = 17.1 lbs.

p' = 38.5 psi

S' = 0.75 (assumed for particles in soil)

Plugging in variables,

$F_{vert} = [(\pi)(d^2)p']S'$
$17.1 = [(\pi)(d^2)(38.5\text{ psi})](0.75)$
$d^2 = .189$
$d = .43\text{ in}$

Therefore, the maximum particle size should be limited to, $\mathbf{d_{max} = 7/16"}$

CONCLUSIONS

Assuming the following:

- the construction loads do not exceed 17.6 psi; and
- the rebar supports are 2"x 2" masonry blocks, spaced 5 ft. on center.

A heat bonded nonwoven carrier geotextile with a puncture strength greater than 41 lbs. will be adequate for protection of the Liquid Boot geomembrane. A nonwoven needle-punched cushion geotextile with a puncture strength greater than 116 lbs. will be adequate for protection of the Liquid Boot geomembrane.

• COMPLETE SET OF GEOTEXTILE PROPERTIES

Typical Typar 3401 heat bonded nonwoven carrier geotextile, when subjected to laboratory testing, should provide the following mechanical property values:

Property	Value
puncture strength	> 41 lb.
grab strength	> 130 lb.
burst strength	> 140 psi
trapezoidal tear	> 60 lb.
ultraviolet strength retention	> 70 %

Typical nonwoven needle-punched 10 oz/yd^2 cushion geotextile, when subjected to laboratory testing, should provide the following mechanical property values:

Property	Value
puncture strength	> 116 lb.
grab strength	> 250 lb.
burst strength	> 460 psi
trapezoidal tear	> 100 lb.
ultraviolet strength retention	> 70 %

• GEOTEXTILE PRODUCTS THAT MEET REQUIREMENTS

The following is a partial list of geotextile products that meet the property values stated above for carrier geotextile:

- Linq Typar 3401

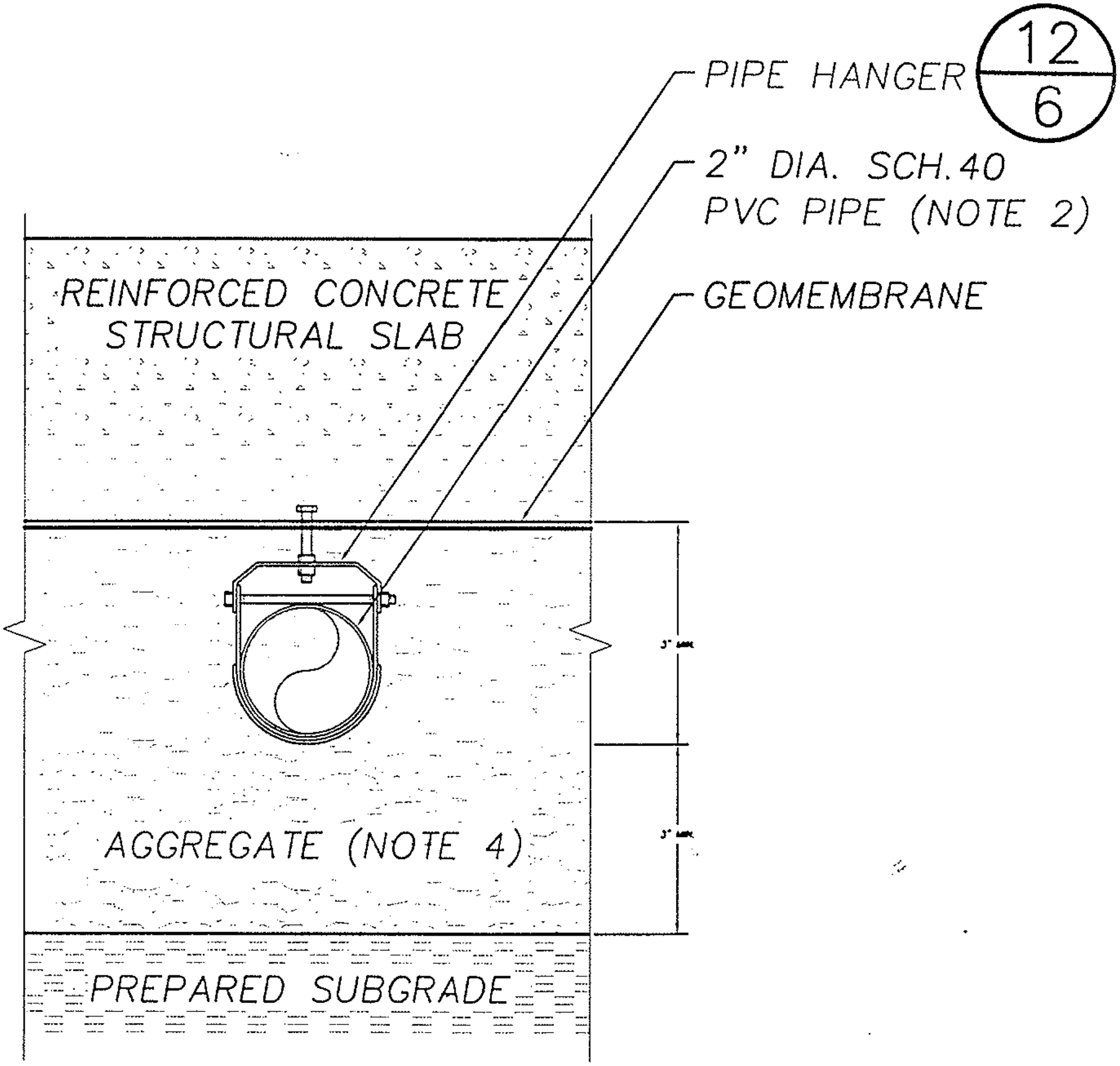
The following is a partial list of geotextile products that meet the property values stated above for cushion geotextile:

- Amoco 4510
- Linq 275EX
- Synthetic Industries Geotex 1001
- TC Mirafi 1100N

REFERENCES

ACI 318-95 and ACI 318-95R "Building Code Requirements for Structural Concrete and Commentary," American Concrete Institute, Farmington Hills, MI, USA

Koerner, R.M. (1990) "Designing with Geosynthetics", 2nd Edition, Prentice Hill, New Jersey.



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SECTION
GAS EXTRACTION SYSTEM
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APPENDIX E — STEEL REINFORCEMENT INFORMATION

As an aid to users of the ACI Building Code, information on sizes, areas, and weights of various steel reinforcement is presented.

ASTM STANDARD REINFORCING BARS

Bar size, no.	Nominal diameter, in.	Nominal area, in.^{2}	Nominal weight, lb/ft
3	0.375	0.11	0.376
4	0.500	0.20	0.668
5	0.625	0.31	1.043
6	0.750	0.44	1.502
7	0.875	0.60	2.044
8	1.000	0.79	2.670
9	1.128	1.00	3.400
10	1.270	1.27	4.303
11	1.410	1.56	5.313
14	1.693	2.25	7.650
18	2.257	4.00	13.600

ASTM STANDARD PRESTRESSING TENDONS

Type*	Nominal diameter, in.	Nominal area, in.^{2}	Nominal weight, lb/ft
Seven-wire strand (Grade 250)	1/4 (0.250)	0.036	0.122
	5/16 (0.313)	0.058	0.197
	3/8 (0.375)	0.080	0.272
	7/16 (0.438)	0.108	0.367
	1/2 (0.500)	0.144	0.490
	(0.600)	0.216	0.737
Seven-wire strand (Grade 270)	3/8 (0.375)	0.085	0.290
	7/16 (0.438)	0.115	0.390
	1/2 (0.500)	0.153	0.520
	(0.600)	0.217	0.740
Prestressing wire	0.192	0.029	0.098
	0.196	0.030	0.100
	0.250	0.049	0.170
	0.276	0.060	0.200
Prestressing bars (plain)	3/4	0.44	1.50
	7/8	0.60	2.04
	1	0.78	2.67
	1-1/8	0.99	3.38
	1-1/4	1.23	4.17
	1-3/8	1.48	5.05
Prestressing bars (deformed)	5/8	0.28	0.98
	3/4	0.42	1.49
	1	0.85	3.01
	1-1/4	1.25	4.39
	1-3/8	1.58	5.56

* Availability of some tendon sizes should be investigated in advance.

Attachment B 1/1

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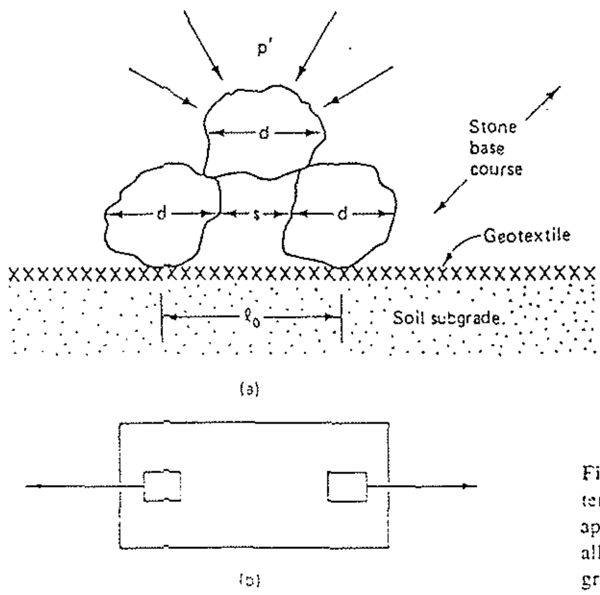

Figure 2.26 Geotextile being subjected to tensile (Grab) stress as surface pressure is applied and stone base tends to spread laterally. (a) Actual situation. (b) Analogous grab tension test.

2.5.4 Puncture (Tear) Resistance

Although not only related to the separation function, the geotextile during its placement must survive the installation process. Indeed, fabric survivability is critical in all types of applications; without it, the best of designs are futile (recall Section 2.2.6.1). In this regard, sharp stones, tree stumps, roots, miscellaneous debris, and other things on the ground beneath the geotextile could puncture through the fabric after stone base and traffic loads are imposed above it. The design method suggested for this situation is shown schematically in Figure 2.27. For these conditions, the vertical force exerted on the geotextile (which is gradually tightening around the object) is as follows:

$$F_{\text{vert}} = [(\pi d_h)\,(h_h)\,q']S' \qquad (2.26)$$

where

F_{vert} = the total vertical force imposed on the fibers adjacent to the puncture;

d_h = the average diameter of the hole, where d_h (maximum) = d_a = average diameter of the aggregate (or stump, etc.);

h_h = the propagation height ($\approx d_a$);

p' = the pressure exerted on the geotextile (usually 75% to 100% of tire inflation pressure at the ground surface); and

S' = the shape factor varying from 0 for rounded blunt objects to 1.0 for sharp angular objects (for aggregate particles, the shape factor can be assumed to be $(1.0 - S)$, where S is the sphericity, from $S = A_p/A_c$, where A_p is the projected area of the particle and A_c is the area of the smallest circumscribing circle around the particle; typical values of S are 0.8 for Ottawa sand, 0.7 for run-of-bank gravel, 0.4 for crushed rock, and 0.3 for shot rock).

This vertical force must now be converted into a tensile force in the fibers of the geotextile. This is indeed a complex problem, since both radial friction and axial rotation of the fibers against the protrusion are involved. As an approximation, however, we can use

$$\frac{F_{\text{vert}}}{T_{\text{reqd}}} = \frac{d_a}{d_i} \tag{2.27}$$

where

F_{vert} = the total vertical force on fibers,
T_{reqd} = the required tensile force in fibers,
d_a = the average diameter of the stone, and
d_i = the initial average void diameter of geotextile.

Combining equations, with the assumptions noted above, one obtains

$$T_{\text{reqd}}\left(\frac{d_a}{d_i}\right) = (\pi d_a^2 p')S'$$

$$T_{\text{reqd}} = (\pi d_i d_a)\, p'S' \tag{2.28}$$

This value of T_{reqd} can be compared to the puncture test (if the object is blunt, causing puncture) or to the tear test (if the object is sharp, causing tear). Both types of tests were described in Section 2.2.3.

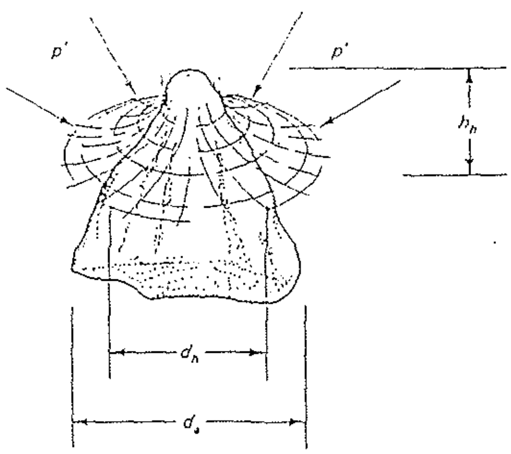

Figure 2.27 Visualization of a stone puncturing a geotextile as pressure is applied from above.

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Attachment C 2/3

TABLE 2.12 RECOMMENDED PARTIAL FACTOR OF SAFETY VALUES FOR USE IN EQUATION 2.18

Application area	Various partial factors of safety: Installation damage	Creep*	Chemical degradation	Biological degradation
separation	1.1 to 2.5	1.0 to 1.2	1.0 to 1.5	1.0 to 1.2
cushioning	1.1 to 2.0	1.2 to 1.5	1.0 to 2.0	1.0 to 1.2
unpaved roads	1.1 to 2.0	1.5 to 2.5	1.0 to 1.5	1.0 to 1.2
walls	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5	1.0 to 1.3
embankments	1.1 to 2.0	2.0 to 3.0	1.0 to 1.5	1.0 to 1.3
bearing capacity	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5	1.0 to 1.3
slope stabilization	1.1 to 1.5	1.5 to 2.0	1.0 to 1.5	1.0 to 1.3
pavement overlays	1.1 to 1.5	1.0 to 1.2	1.0 to 1.5	1.0 to 1.1
railroads	1.5 to 3.0	1.0 to 1.5	1.5 to 2.0	1.0 to 1.2
flexible forms	1.1 to 1.5	1.5 to 3.0	1.0 to 1.5	1.0 to 1.1
silt fences	1.1 to 1.5	1.5 to 2.5	1.0 to 1.5	1.0 to 1.1

*The low end of the range refers to results that have been compensated for creep in the performance of the tests.

$$T_{\text{allow}} = T_{\text{ult}}\left(\frac{1}{FS_{ID} \times FS_{CR} \times FS_{CD} \times FS_{BD}}\right) \tag{2.18}$$

where

T_{allow} = the allowable tensile strength,
T_{ult} = the ultimate tensile strength,
FS_{ID} = the factor of safety for installation damage,
FS_{CR} = the factor of safety for creep,
FS_{CD} = the factor of safety for chemical degradation, and
FS_{BD} = the factor of safety for biological degradation. (close to 1)

Note that this equation could just as well have been formulated as fractional multipliers (≤ 1.0) and placed in the numerator of the equation. It is placed in this form because other studies have done likewise (e.g., Voskamp and Risseeuw [37]). While the equation indicates tensile strength, it can equally well be applied to burst strength, tear strength, puncture strength, seam strength, etc.

For problems dealing with flow through or within a geotextile, the formulation takes the following form with typical values given in Table 2.13. Note that these values must be tempered with site-specific conditions as was the case with the previous table.

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{FS_{SCB} \times FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC}}\right) \tag{2.19}$$

Attachment C 3/3

GEOTEXTILES

Product Name (Structure [1]/ Polymer Type [2])	Mass Per Unit Area ASTM D 5261 g/m² (oz/yd²)	H288 Transportation-Related Applications: Filtration/Hydraulic Properties: Percent Open Area CWO-22125 %	Apparent Opening Size ASTM D 4751 mm (U.S. sieve)	Permittivity ASTM D 4491 sec⁻¹ Flow Rate (FH or CH) [3] l/min/m² (gal/min/ft²)	Physical Properties: Puncture ASTM D 4833 kN (lb)	Trapezoid Tearing Strength ASTM D 4533 kN (lb)	Grab Tensile/ Elongation ASTM D 4632 kN (lb)/%	H288 Survivability Class	H288 Applications [4]	Reinforcement Applications: Wide Width Tensile Properties ASTM D 4595 kN/m (lb/in.): Strength @ 5% Strain [5] MD	Strength @ 5% Strain [5] XD	Ultimate Strength % (T_{ult}) [5] MD	Ultimate Strength % (T_{ult}) [5] XD	Creep Limited Strength ASTM D 5262 [7] kN/m (lb/ft)	T_{allow} GRI GT7 (in sand) [6]	Other Manufacturer's Suggested Applications [8]

LINQ Industrial Fabrics Inc.

Product Name	Mass Per Unit Area	Percent Open Area	Apparent Opening Size	Permittivity / Flow Rate	Puncture	Trapezoid Tearing Strength	Grab Tensile/ Elongation	H288 Survivability Class	H288 Applications	Strength @ 5% MD	Strength @ 5% XD	Ultimate MD	Ultimate XD	Creep Limited Strength	T_{allow}	Other Applications
Typar 3341 (NW-PP)	NP	NP	0.25 (60)	0.70, FH	0.134 (30)	0.178 (40)	0.534 (120)/60	—	—	NP	NP	NP	NP	NP	NP	F, D
Typar 3401 (NW-PP)	NP	NP	0.21 (70)	0.70, FH	0.180 (41)	0.267 (60)	0.579 (130)/60	3	SP, ST, D	NP	NP	NP	NP	NP	NP	S/S, F, D
Typar 3501 (NW-PP)	NP	NP	0.21 (70)	0.70, FH	0.250 (56)	0.265 (60)	0.710 (160)/60	2	SP, ST, D	NP	NP	NP	NP	NP	NP	S/S, F, D
Typar 3631 (NW-PP)	NP	NP	0.106 (140)	0.20, FH	0.355 (80)	0.401 (90)	1.113 (250)/60	1	ST, E	NP	NP	NP	NP	NP	NP	S/S, F, D
125EX (NW-PP)	NP	NP	0.21 (70)	1.6, FH	0.244 (55)	0.178 (40)	0.401 (90)/50	—	—	NP	NP	NP	NP	NP	NP	A/O, F, D
130EX (NW-PP)	NP	NP	0.21 (70)	1.4, FH	0.267 (60)	0.200 (45)	0.467 (105)/50	—	—	NP	NP	NP	NP	NP	NP	A/O, F, D
140EX (NW-PP)	NP	NP	0.21 (70)	1.1, FH	0.289 (65)	0.222 (50)	0.534 (120)/50	3	SP, ST D, A/O	NP	NP	NP	NP	NP	NP	S/S, F, D
150EX (NW-PP)	NP	NP	0.18 (80)	1.1, FH	0.401 (90)	0.289 (65)	0.734 (165)/50	2	ST, ST, D	NP	NP	NP	NP	NP	NP	S/S, F, D
160EX (NW-PP)	NP	NP	0.18 (80)	1.1, FH	0.401 (90)	0.312 (70)	0.801 (180)/50	—	—	NP	NP	NP	NP	NP	NP	S/S, F, D

[1] NW = Nonwoven, -P = needlepunched, -h = calendered
W = Woven, -SF = slit film
K = Knitted O/C = Other/combination
[2] PP = Polypropylene PET = Polyester
[3] FH = Test is run by the falling head method
CH = Test is run by the constant head method
[4] SP = Separation S/F = Silt Fence
ST = Stabilization D = Drainage

F = Filtration E = Erosion Control
A/O = Asphalt overlay
[5] MD = Machine direction XD = Cross-machine direction
[6] $T_{allow} = \frac{T_{ult}}{RF_{CR} \times RF_{ID} \times RF_D}$
RF_{CR} = Reduction factor for creep
RF_{ID} = Reduction factor for installation damage
RF_D = Reduction factor for durability

NOTE: This equation does not include other reduction factors which may apply to design. Reduction factors are site specific and should be reviewed on a per project basis. Contact the manufacturer for recommendations.
[7] For a minimum of 10,000 hours, extrapolated to a 75-year time period
[8] R = Reinforcement P = Protection
RC = Reinforcement Composite

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