SIMPLIFIED DESIGN CHARTS FOR GEOMEMBRANE OR GCL CUSHIONS

The attached technical note from Synthetic Industries, Inc., discusses the use of non-woven, needlepunched geotextiles as cushions to protect geomembranes from damage from cover soils or subgrade materials. The authors describe a partially empirical, partially theoretical procedure for selecting appropriate protective geotextiles. The method, which was originally developed by Robert Koerner at Drexel University, was used to develop simplified design charts for common waste and liquid containment applications. Three examples are also provided.

Although specifically developed for geomembranes, the same geotextile cushioning design practice can be used for GCLs that may be subject to damage from large stones in either cover soils or the subgrade. As discussed in our Installation Guidelines (TR-402), CETCO recommends a protective cushion if angular particles in the soil covering the GCL are expected to exceed a diameter of 1 inch. According to the landfill design charts, in landfills less than 50 feet in height, if angular stones between 1 and 1.5 inches in diameter are expected in the soil covering the GCL, a 12 oz/yd^2 geotextile cushion is recommended. According to the pond design charts, in ponds shallower than 50 feet, if subangular stones approximately 1 inch in diameter are expected in the subgrade soils beneath the GCL, a 20 oz/yd^2 geotextile cushion is recommended.

Prior to applying the design charts, the reader should review and understand the limitations and assumptions discussed in the referenced literature. The authors caution that the design procedure may not be conservative for construction (dynamic) loads. In cases where dynamic loads are expected, or where site-specific conditions deviate significantly from the simplifying assumptions used in the cushioning design procedure, project-specific lab testing or field plots are recommended.

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SIMPLIFIED DESIGN CHARTS FOR GEOMEMBRANE CUSHIONS

STEPHEN N. VALERO, P.E. – SYNTHETIC INDUSTRIES, INC. (USA)
DERON N. AUSTIN, P.E. – SYNTHETIC INDUSTRIES, INC. (USA)

ABSTRACT

Recent and ongoing research indicates that use of a properly selected nonwoven, needle-punched geotextile cushion adjacent to (above and/or below) a geomembrane can effectively protect it from construction and operational damage. The current practice selects an appropriate geotextile cushion using the Geosynthetic Research Institute (GRI) method (Koerner, et. al. 1996). This method was used to develop simplified design charts allowing quick, conservative selection of an appropriate geotextile cushion. Charts are provided for typical applications including solid waste landfills and liquid impoundments with varying load, subgrade and cover/subgrade soil conditions. In addition, a brief discussion of the design procedure is provided with completed numerical examples.

INTRODUCTION

Most solid and hazardous waste landfills, lagoons and reservoirs built today incorporate geomembranes to contain liquids. Although these low permeability liners have demonstrated excellent performance, they are susceptible to damage when drainage stone or alternate drainage media (such as shredded tires, crushed glass, etc.) are placed over them (Figure 1). In addition, geomembranes are prone to damage from isolated protrusions present in the subgrade onto which they are deployed.

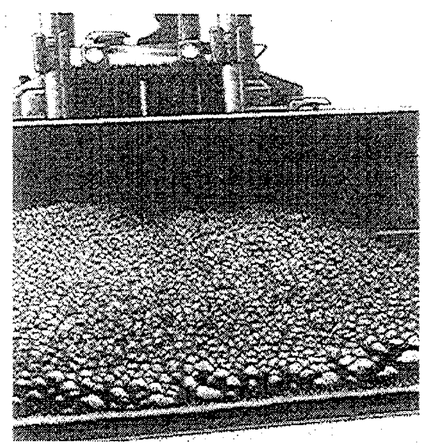

Figure 1. Stone Placement over a Geomembrane

Figure 2 illustrates the typical components of modern landfill liner system and Figure 3 represents a typical liquid impoundment liner system. Of these components, the geomembrane is the most prone to damage. Protecting the geomembrane from tearing or puncturing during construction and operation is critical. Recent and ongoing research indicates that deployment of a properly selected nonwoven, needle-punched geotextile cushion adjacent to (above and/or below) a geomembrane provides effective protection against damage.

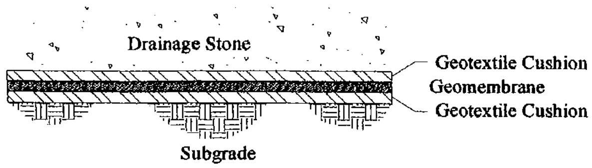

Figure 2. Typical Municipal Landfill Liner System

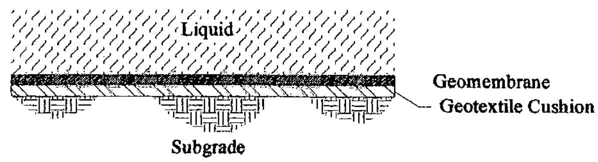

Figure 3. Typical Liquid Impoundment Liner System

STATE OF GEOMEMBRANE CUSHION DESIGN PRACTICE

State of geomembrane cushion design practice suggests using the generalized procedure developed by Koerner, et. al (1996) at the Geosynthetic Research Institute (GRI). The GRI method couples theoretical (Wilson-Fahmy, et. al., 1996) and empirical (Narejo, et. al., 1996) puncture protection analysis through use of a global factor of safety. The method directly applies to 1.5 mm (60 mil), smooth, high density polyethylene (HDPE) geomembranes protected by virgin polymer, nonwoven, needle-punched geotextiles. However, early work by Hullings and Koerner (1991) and field research by Richardson and Johnson (1998) indicate that the method may be conservative for geomembranes manufactured from more flexible polymers. Koerner, et. al. (1996) also suggest that the GRI method may be extended to other types of cushion materials.

The governing equation (Equation 1) incorporates several simplifying assumptions. For extrapolation to field design, (at least partially) subjective modification/reduction factors are required. In addition, laboratory testing used to develop the model did not incorporate dynamic loading. Therefore, the GRI method is considered adequate in cases where uniform, normal, static loading controls the design (i.e. moderate to high waste fills and most liquid impoundments) and may be under-conservative in cases where construction (dynamic) loading controls (i.e. shallow waste fills, poor construction practices, etc.). Based on field evaluation of geosynthetic cushions under construction loading, Richardson (1996) recommends modification of the GRI method such that the minimum nonwoven geotextile cushion mass selected is 405 g/m^2 (12 oz/yd^2) for 2.5 cm (1 in) maximum gravel over smooth HDPE geomembranes. This recommendation was later extended to 1.3 cm (0.5 in) gravel through additional field testing (Richardson and Johnson, 1998). Reddy et. al. (1996) performed similar field evaluations and concluded that a lighter 270 g/m^2 (8 oz/yd^2) geotextile is capable of providing adequate protection against construction loading. Based on laboratory testing, Reddy and Saichek (1998) also concluded that a 270 g/m^2 (8 oz/yd^2) may provide acceptable long-term protection under specific conditions.

Although a comprehensive review of previous research is beyond the scope of this paper, the reader is encouraged to read and understand the referenced literature prior to application or modification of the GRI method. This methodology (that forms the basis for the simplified design charts presented later in this paper) is summarized in the following steps.

Step 1: Estimate the Allowable Pressure on the Geomembrane (in terms of M_A)

$$P'_{allow} = \left(450 \cdot \frac{M_A}{H^2}\right)\left(\frac{1}{MF_S \cdot MF_{PC} \cdot MF_A}\right)\left(\frac{1}{FS_{CR} \cdot FS_{CBD}}\right) \qquad \text{(Equation 1)}$$

Where:

P'_{allow} = Allowable pressure on geomembrane (kPa)
450 = Empirical constant ($kPa \cdot mm^2/(g/m^2)$)
M_A = Required mass per unit area of nonwoven, needle-punched geotextile (g/m^2)
H = Effective height of protrusion (mm)
MF_S = Modification factor for protrusion shape (dimensionless)
MF_{PC} = Modification factor for protrusion configuration (dimensionless)
MF_A = Modification factor for overburden arching effect (dimensionless)
FS_{CR} = Factor of safety for geotextile creep (dimensionless)
FS_{CBD} = Factor of safety for geotextile chemical/biological degradation (dimensionless)

Equation 1 should be solved in terms of M_A. The effective height of protrusion (H) represents the maximum height of any object in contact with the geomembrane extends relative to the overlying/underlying media. In cases where protection is sought from uniformly packed stones (such as landfill leachate collection/drainage media), H may be estimated as one-half the maximum particle diameter of the stones. However, when protection is sought from isolated protrusions (such as stones encountered in a hastily prepared subgrade), H may be estimated as the maximum particle diameter of the protrusions. In the later case, the value of H may be based on observed conditions, or specified by restricting the largest particle size allowed to remain on the prepared subgrade during geosynthetic deployment. Modification Factors for protrusion shape, protrusion configuration, and overburden arching effect may be selected based on guidelines presented by Narejo, et. al (1996):

Table 1. Recommended Modification Factor for Protrusion Shape
(Adapted from Narejo, et. al., 1996, page 647)

Protrusion Shape	Modification Factor, MF_S
Angular	1.00
Subrounded	0.50
Rounded	0.25

Table 2. Recommended Modification Factor for Protrusion Configuration
(Adapted from Narejo, et. al., 1996, page 647)

Protrusion Configuration	Modification Factor, MF_{PC}
Isolated Protrusions	1.00
Uniformly Packed Surface	0.50

Table 3. Recommended Modification Factor for Overburden Arching Effect
(Adapted from Narejo, et. al., 1996, page 648)

Anticipated Arching Effect	Modification Factor, MF_A
None (i.e. Liquid Overburden)	1.00
Moderate	0.50
Maximum	0.25

Through limited creep testing, Narejo, et. al. (1996) indicated that geotextile cushion creep is primarily a function of H and M_A. Since M_A is unknown at this point, Equation 1 may be solved by assuming a reasonable value for FS_{CR} based on the anticipated M_A required. Following completion of the required calculations, the assumed value of FS_{CR} must be checked for validity. Table 4 provides recommended FS_{CR} values in the form of unique linear equations for several commonly available nonwoven, needle-punched geotextiles. It is interesting to note that the recommended upper limit with respect to H, is in general agreement (probably by coincidence) with construction limits established by Richardson (1996) and Reddy and Saichek (1996). The equations for FS_{CR} and their range of validity were interpolated/extrapolated from available geotextile cushion creep test data (Narejo, et. al., 1996).

Table 4. Factor of Safety for Geotextile Creep
(Adapted from Narejo, et. al., 1996, page 644 - 648)

Nonwoven, Needle-punched Geotextile Mass per Unit Area	Factor of Safety, FS_{CR}
270 g/m^2 (N/R for H > 12 mm)	$\gtrsim 0.0417 \cdot H + 1.25$
405 g/m^2 (N/R for H > 19 mm)	$\gtrsim 0.0292 \cdot H + 1.18$
540 g/m^2 (N/R for H > 25 mm)	$\gtrsim 0.0166 \cdot H + 1.11$
675 g/m^2 (N/R for H > 29 mm)	$\gtrsim 0.0139 \cdot H + 1.08$
745 g/m^2 (N/R for H > 31 mm)	$\gtrsim 0.0129 \cdot H + 1.07$
810 g/m^2 (N/R for H > 32 mm)	$\gtrsim 0.0119 \cdot H + 1.06$
945 g/m^2 (N/R for H > 35 mm)	$\gtrsim 0.0100 \cdot H + 1.03$
1015 g/m^2 (N/R for H > 36 mm)	$\gtrsim 0.0089 \cdot H + 1.02$
1080 g/m^2 (N/R for H > 38 mm)	$\gtrsim 0.0080 \cdot H + 1.00$

NOTE: N/R = Not recommended

The factor of safety for chemical and biological degradation (FS_{CBD}) should be selected based on the aggressiveness of the anticipated chemical environment and the geotextile polymer composition. Table 5 provides general recommendations:

Table 5. Recommended Factor of Safety for Chemical and Biological Degradation (based on Koerner, 1994, page 151 and Synthetic Industries, 1997)

Chemical Environment	Factor of Safety for Chem/Bio Degradation, FS_{CBD}	
	Polyester (PET) Geotextiles	Polypropylene (PP) Geotextiles
Normal (i.e. $3 < pH < 10$)	1.0	1.0
Aggressive ($pH < 3$ or $pH > 10$)	1.5 – 2.0	1.0 – 1.5

Step 2: Estimate the Anticipated Pressure on the Geomembrane

$$P_{actual} = \gamma \cdot h \qquad \text{(Equation 2)}$$

Where:

γ = Unit weight of overburden material or liquid (kN/m^3)
h = Design height of overburden material or liquid depth (m)
P_{actual} = Estimated maximum pressure on geomembrane (kPa)

The parameters required to complete Equation 2 may be assumed or specified based on site specific considerations. The unit weight of typical municipal solid waste may be estimated to equal 12.56 kN/m^3 (80 lb/ft^3) in the absence of site specific data. Likewise, the unit weight of most liquids can be approximated by the unit weight of water, 9.81 kN/m^3 (62.4 lb/ft^3).

In some cases (i.e. shallow waste fills, poor construction practices, etc.), the dynamic forces associated with construction loading may exceed those associated with long-term static loading. The exact point at which this occurs is dependent on multiple variables and difficult (if not impossible) to estimate. Therefore, caution should be exercised in selection of a geotextile cushion having a mass per unit area less than 405 g/m^2 (12 oz/yd^2), the construction limit recommended by Richardson and Johnson (1998).

Step 3: Calculate the Required Mass per Unit Area of the Cushion Geotextile

$$P'_{allow} \geq FS_{g\,min} \cdot P_{actual} \qquad \text{(Equation 3)}$$

Where:

P'_{allow} = Allowable pressure on geomembrane in terms of M_A (Equation 1)
FS_{gmin} = Global Factor of Safety (dimensionless)

Equation 3 may be solved for M_A through substitution (Equation 1 and 2 results) and algebraic manipulation. The global factor of safety (FS_{gmin}) should be selected based on the protrusion configuration and H. Recommendations are provided in Table 6.

Table 6. Recommended Global Factor of Safety
(Adapted from Koerner, et. al., 1996, page 648)

Protrusion Configuration	Global Factor of Safety, FS_{gmin}
Isolated Protrusions	$= 0.22 \cdot H + 1.77$ ($\geqq 3.0$)
Uniformly Packed Surface	3.0

Step 4: Select Appropriate Geotextile Cushion

Select a nonwoven, needle-punched geotextile having a minimum average roll value (MARV) M_A greater than or equal to that calculated in Step 3. It should be noted that the method presented herein is based on limited testing (Narejo, et. al, 1996) using virgin polymer, nonwoven, needle-punched geotextile and may not apply to all types of geotextiles and cushion materials.

Step 5: Check Assumed Value of FS_{CR} and Construction Limits

In Step 1, FS_{CR} was assumed to allow solution of Equation 1. Check Table 4 to ensure that the assumed value is valid for the geotextile selected in Step 4 (If not, revise FS_{CR} and repeat Steps 1 through 4).

In cases where solid material (i.e. rock, solid waste, etc.) will be placed on top of the geomembrane with heavy equipment, construction loading must be considered. Based on field experimentation, the minimum M_A geotextile should be between 270 g/m^2 (8 oz/yd^2) (Reddy, et. al., 1996) and 405 g/m^2 (12 oz/yd^2) (Richardson and Johnson, 1998) to prevent construction damage. The reader should review and understand both documents prior to selecting a geotextile having M_A less than 405 g/m^2.

SIMPLIFIED GEOMEMBRANE CUSHION SELECTION CHARTS

A series of simplified design charts have been developed for the most common geomembrane cushioning applications based on the methodology presented. These charts allow the user to quickly and conservatively select an appropriate virgin polymer, nonwoven, needle-punched geotextile cushion. The applicability and assumptions associated with these charts are provided in the notes section of each figure. In addition, the reader is encouraged to review and understand the limitations of the GRI method (discussed in the referenced literature) prior to application the charts on the following pages. Figures 4 through 7 present charts for landfill applications while Figures 8 and 9 relate to liquid impoundment applications.

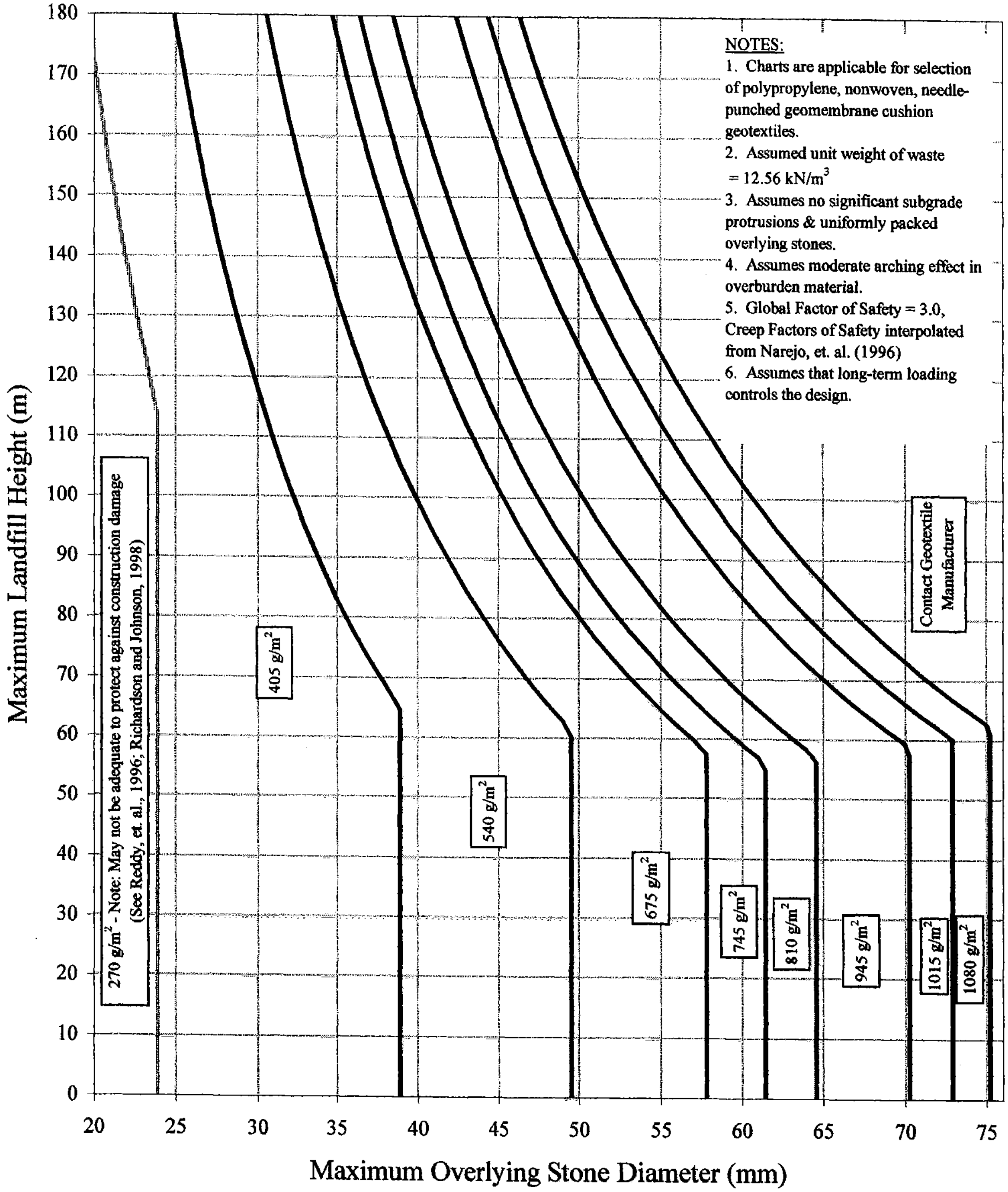

Figure 4. Geomembrane Cushion Selection Chart - Landfill Application, Rounded Overlying Stones (SI Units)

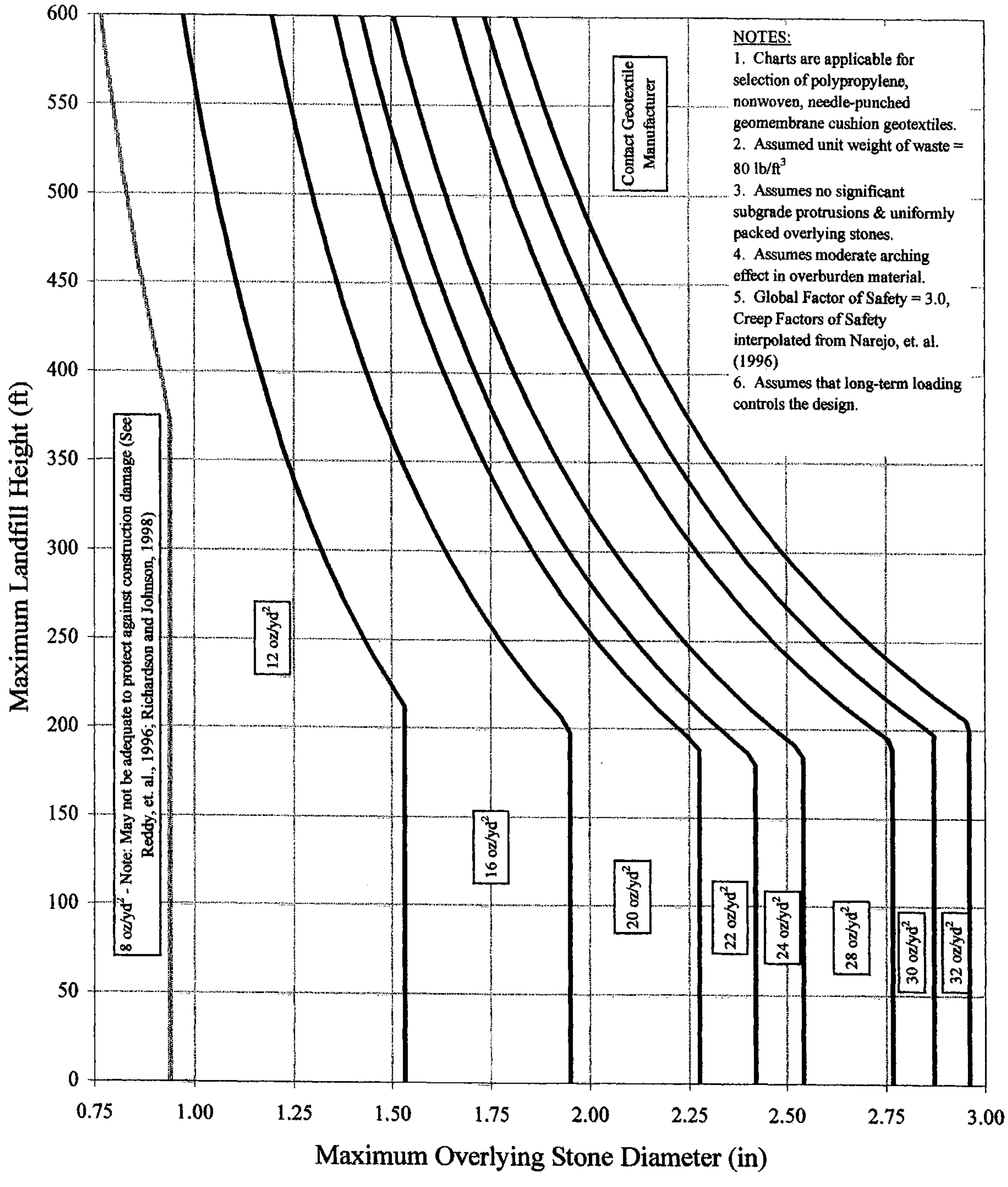

Figure 5. Geomembrane Cushion Selection Chart - Landfill Application, Rounded Overlying Stones (US Units)

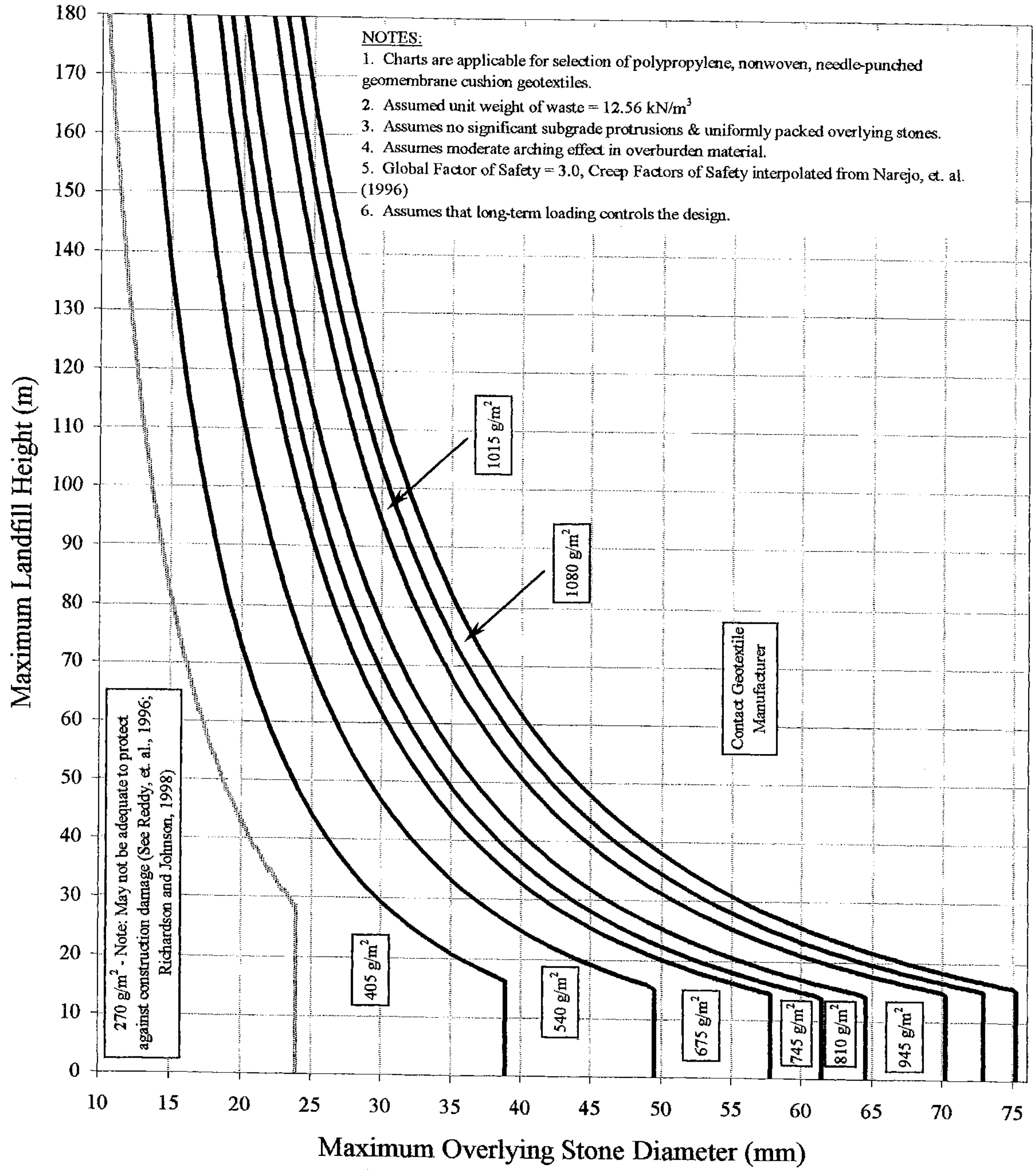

Figure 6. Geomembrane Cushion Selection Chart - Landfill Application, Angular Overlying Stones (SI Units)

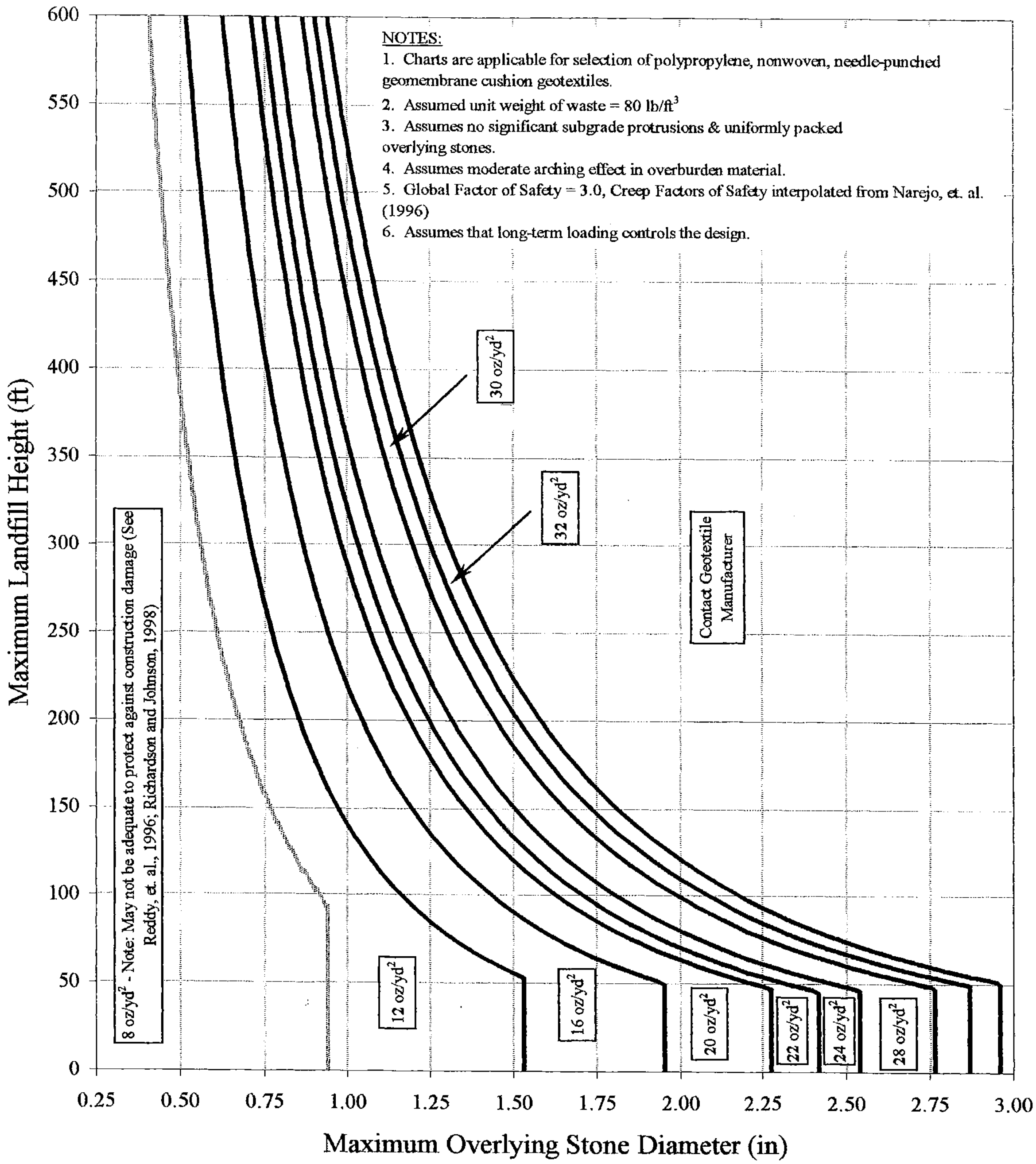

Figure 7. Geomembrane Cushion Selection Chart - Landfill Application, Angular Overlying Stones (US Units)

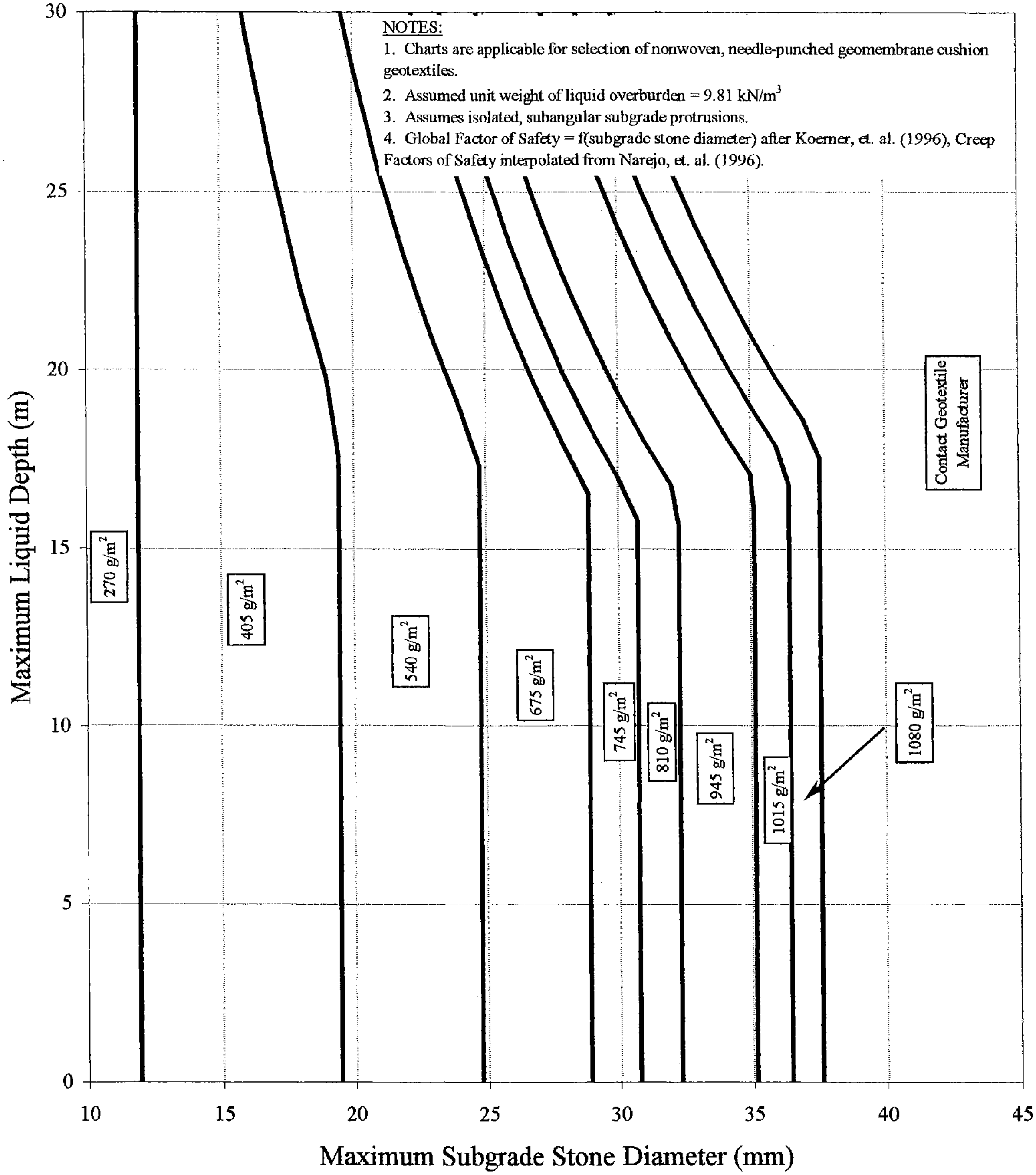

Figure 8. Geomembrane Cushion Selection Chart - Liquid Impoundment Application, Subangular Subgrade Stones (SI Units)

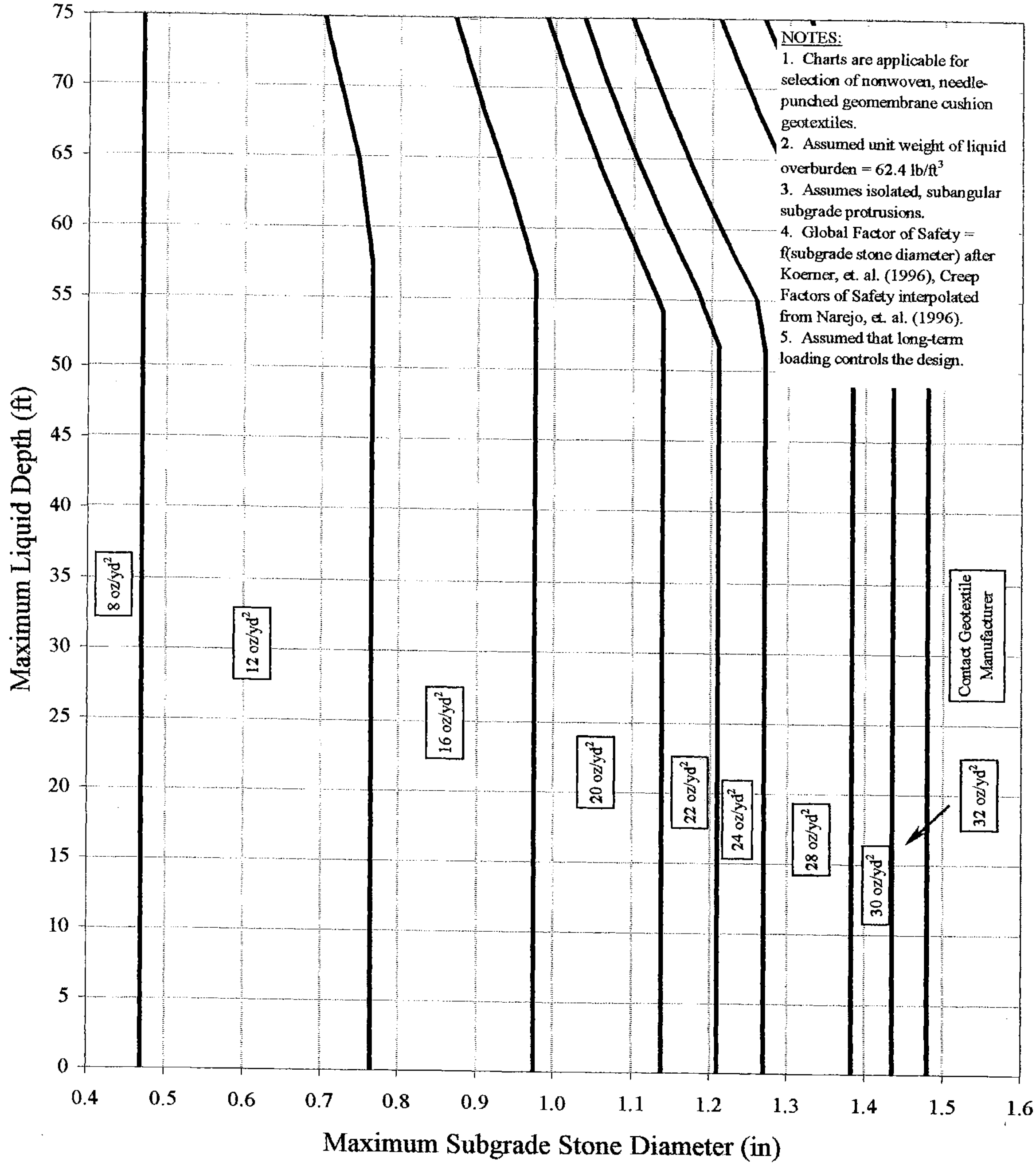

Figure 9. Geomembrane Cushion Selection Chart - Liquid Impoundment Application, Subangular Subgrade Stones (US Units)

EXAMPLES

The following simple design examples illustrate application of the charts and GRI method to three common geomembrane cushion applications. Examples 1 and 2 illustrate selection of a geotextile cushion using Figures 4 through 9. Example 3 depicts selection of a geotextile cushion for conditions other than those represented by the charts.

Example 1: Municipal Landfill Liner Cushion

A municipal solid waste (MSW) landfill cell is to be constructed over a carefully prepared subgrade (no significant isolated protrusions). The leachate collection media (to be placed above the geomembrane) is angular crushed stone with a maximum diameter of 38 mm (1.5 in). The maximum design height of the cell is 80 m (262.5 ft). Select an appropriate geotextile to protect the geomembrane.

Solution 1:

Using the design charts in Figures 4 or 5 select a needle-punched, nonwoven, polypropylene geotextile having a MARV M_A of at least 540 g/m^2 (16 oz/yd^2).

Example 2: Liquid Impoundment Liner Cushion

A liquid impoundment is to be constructed over a subgrade containing isolated, angular stone protrusions. The impoundment is to be lined with a geomembrane underlain by a 540 g/m^2 (16.0 oz/yd^2) needle-punched, nonwoven, polypropylene geotextile for protection against the subgrade stones. No stone or other solid material will be placed on the geomembrane. Therefore, construction loading is not a concern. It is anticipated that the maximum liquid depth will be 20 m (65.6 ft). For specification purposes, determine the largest stone which may safely remain on the subgrade without damaging the geomembrane.

Solution 2:

Based on the design charts in Figures 8 or 9, stones larger than 23 mm (0.9 in) in diameter might damage the geomembrane. Thus, the construction specification could be written to require removal of all protruding subgrade stones larger than approximately 25 mm (1 in).

Example 3: Industrial Landfill Liner Cushion

A portion of the cell described in Example 1 is to be used as a monofill for automobile shredder fluff (average unit weight equal to 10.2 kN/m^3 (65 lb/ft^3)). This portion of the cell is design to be filled to a height of 25 m (82 ft). In addition, a finer 25 mm (1 in) angular, crushed stone will be used for leachate collection media. Assuming all other liner components (except the cushion) remain unchanged, select an appropriate geotextile to protect the geomembrane.

Solution 3:

The design charts are not applicable to this problem since $\gamma \neq 12.6$ kN/m^3 (80 lb/ft^3). In addition, construction loading may control geotextile selection given the relatively shallow fill height and low unit weight of waste. Consequently, the problem must be solved by equation.

A. Determine P'_{allow} in terms of M_A, where:

H	= ½ of maximum overlying particle diameter = 12.5 mm
MF_S	= 1.0 (Table 1 - angular stone)
MF_{PD}	= 0.5 (Table 2 - uniformly packed surface)
MF_A	= 0.75 (Table 3 - moderate arching of waste materials)
FS_{CR}	= 1.6 (assumed, corresponds to 270 g/m^2 - to be checked against Table 4)
FS_{CBD}	= 1.2 (Table 5 - polypropylene geotextile in waste application)

$$P'_{allow} = \left(450 \cdot \frac{M_A}{12.5^2}\right)\left(\frac{1}{1.0 \cdot 0.5 \cdot 0.75}\right)\left(\frac{1}{1.6 \cdot 1.2}\right) = 4.0 \cdot M_A$$

B. Determine anticipated pressure on geomembrane, where:

γ	= 10.2 kN/m^3 (given)
h	= 25 m (given)

$$P_{actual} = 10.2 \cdot 25 = 255 \cdot \text{kPa} \quad \text{(Equation 2)}$$

C. Solve for minimum geotextile M_A through manipulation of Equation 3, where:

FS_{gmin}	= 3.0 (Table 6 – uniform packed stones, no isolated subgrade protrusions)
P'_{allow}	= 4.0· M_A (Equation 1)

$4.0 \cdot M_A \geq 3.0 \cdot 255$ (Equation 3) or: $M_A \geq \dfrac{3.0 \cdot 255}{4.0}$

Thus, $M_A \geq 191.3$ g/m^2 (5.7 oz/yd^2)

D. Check result against Creep limits established in Table 4 and Construction Limits:

From Table 4, the minimum acceptable M_A = 405 g/m^2 (12 oz/yd^2). Coincidentally, this agrees with the construction limits recommended by Richardson and Johnson (1998). Thus, select a nonwoven, needle-punched geotextile having a MARV M_A of at least 405 g/m^2. Although, FS_{CR} was selected based on a 270 g/m^2 (8 oz/yd^2) geotextile, the problem need not be reevaluated in this case since a 405 g/m^2 (12 oz/yd^2) geotextile is the minimum acceptable material based on creep limits (Table 4).

SUMMARY AND APPLICABILITY

The design charts and methodology provided herein are intended to provide a quick and conservative method to select an appropriate geomembrane cushion. Prior to applying the design charts or method, the reader should review and understand the limitations and assumptions discussed in the referenced literature. In circumstances where site specific conditions deviate significantly from the research forming the basis for the charts and GRI method, it is recommended that a project specific testing program be conducted and evaluated by a qualified professional. Geosynthetic materials, testing parameters, etc. should be modeled after anticipated field conditions.

REFERENCES

Hullings, D. and Koerner, R.M., 1991, "Puncture Resistance of Geomembranes Using a Truncated Cone Test", Geosynthetics '91 Conference Proceedings, IFAI: Roseville, MN, pp. 273-285.

Koerner, R.M., 1994, "Designing with Geosynthetics", 3rd ed., Prentice-Hall, Inc.: Englewood Cliffs, New Jersey.

Koerner, R.M., Wilson-Fahmy, R.F. and Narejo, D., 1996, "Puncture Protection of Geomembranes Part III: Examples", Geosynthetics International, vol. 3, no. 5, pp. 655-675.

Narejo, D., Koerner, R.M. and Wilson-Fahmy, R.F., 1996, "Puncture Protection of Geomembranes Part II: Experimental", Geosynthetics International, vol. 3, no. 5, pp. 629-653.

Reddy, K.R. and Saichek, R.E., 1998, "Performance of Protective Cover Systems for Landfill Geomembrane Liners Under Long-Term MSW Loading", Geosynthetics International, vol. 5, no. 3, pp. 287-307.

Reddy, K.R., Bandi, S.R., Rohr, J.J., Finy, M., and Siebken, J., 1996, "Field Evaluation of Protective Covers for Landfill Geomembrane Liners Under Construction Loading", Geosynthetics International, vol. 3, no. 6, pp. 679-700.

Richardson, G.N. and Johnson, S., 1998, "Field Evaluation of Geosynthetic Protective Cushions: Phase 2", Geotechnical Fabrics Report, vol. 16, no. 8, Oct.-Nov., pp. 44-49.

Richardson, G.N., 1996, "Field Evaluation of Geosynthetic Protection Cushions", Geotechnical Fabrics Report, vol. 14, no. 2, Mar., pp. 20-25.

Synthetic Industries, 1997, "The Durability of Polypropylene – Nonwoven Geotextiles for Waste Containment Applications - SMART SOLUTIONS® Technical Note, SM-404", Synthetic Industries, Chattanooga, Tennessee.

Synthetic Industries, 1998, "Design and Selection of GEOTEX® Ultra Heavy Weight Nonwoven Geotextiles for Geomembrane Cushioning - SMART SOLUTIONS® Technical Note, SM-116", Synthetic Industries, Chattanooga, Tennessee.

Wilson-Fahmy, R.F., Narejo, and D., Koerner, R.M., 1996, "Puncture Protection of Geomembranes Part I: Theory", Geosynthetics International, vol. 3, no. 5, pp. 605-628.