Technical Note

Puncture protection of PVC geomembranes

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ABSTRACT: This paper presents a design procedure for the puncture protection of polyvinyl chloride (PVC) geomembranes. The puncture resistance 0.5 mm, 0.75 mm, and 1.0 mm thick PVC geomembranes was measured using the truncated cone test in which truncated cones were used as puncture points. The height of the truncated cones are varied to determine the critical cone height (CCH), which is the height at which geomembrane puncture occurs for a given pressure. Critical cone heights are presented for 0.5 mm, 0.75 mm, and 1.0 mm thick PVC geomembranes and used to estimate the required mass per unit area of the geotextile required to protect the geomembrane against puncture. A new modification factor for critical cone height, MF_{CCH}, was developed to reflect the puncture resistance of flexible PVC geomembranes.

KEYWORDS: PVC Geomembrane, Puncture Resistance, Truncated Cone Test, Durability

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1 INTRODUCTION

Geomembranes are used for many applications because of their advantageous physical and mechanical properties. Several geomembrane materials are available, and the appropriate material for a given application varies with the properties required. These properties include tensile strength, flexibility, chemical resistance, seepage reduction, temperature resistance, and puncture resistance.

In particular, geomembrane puncture resistance is important in containment applications because small punctures can reduce the effectiveness of installed geomembranes and thus the containment system. Information is available on the puncture resistance of PVC geomembranes in Stark et al. (2008). This study uses the data presented in Stark et al. (2008) to develop a design procedure for determining the mass per unit area of a cushion geotextile for various PVC geomembrane thicknesses.

2 TESTING MATERIALS AND METHODS

2.1 Geosynthetics Involved in Test Program

Stark et al. (2008) present results of truncated cone tests on three different thicknesses of PVC geomembranes to capture the range of PVC geomembranes typically used in practice. These geomembrane thicknesses include 0.5 mm, 0.75 mm, and 1.0 mm thick PVC geomembranes. The geomembranes were manufactured by Canadian General-Tower, Ltd. of Cambridge, Ontario, Canada. A compilation of these puncture resistance tests results is shown in Figure 1. HDPE geomembrane data obtained by Hullings (1990) and reported by Hullings and Koerner (1991) are also included in Figure 1.

The truncated cone test procedure used to measure the puncture resistance of the PVC geomembranes is similar to ASTM D5514 (1999). The equipment consists of a 0.56 m inside diameter pressure vessel that can accommodate significant pressure. The top of the pressure vessel is clamped to the bottom using 16 clamps to resist the high applied pressure. Stark et al. (2008) present additional testing details.

3 PUNCTURE RESISTANCE DESIGN METHOD PVC GEOMEMBRANES

Based on the data presented in Stark et al. (2008) and the design equation presented by Koerner et al. (1996) and Koerner (1997), an empirical relationship for the allowable pressure for 0.75 mm thick PVC geomembranes to resist puncture was obtained and is:

$$p'_{allow} = \left(450\frac{M_A}{H^2}\right)\left(\frac{1}{MF_S \times MF_{PD} \times MF_A \times MF_{CCH}}\right)\left(\frac{1}{FS_{CR} \times FS_{CBD}}\right) \quad (1)$$

Where:

- p'_{allow} = allowable pressure on the geomembrane (kPa)
- M_A = mass per unit area of cushion geotextile (g/m^2)
- H = effective protrusion height (mm)

MF is a modification factor:

- protrusion shape, MF_S
- packing density, MF_{PD}
- soil arching, MF_A
- critical cone height, MF_{CCH}

and FS is a partial factor of safety for:

- creep, FS_{CR} is a function of M_A and
- chemical and biological degradation, FS_{CBD} equals 1.5.

The results of the long-term puncture tests described in Stark et al. (2008) show that a creep related modification factor is not needed for PVC geomembranes when used without a geotextile. This is due to the PVC geomembrane showing no long-term creep related puncture without the use of a cushion geotextile in the truncated cone tests. When a PVC geomembrane is used with a cushion geotextile, it is recommended that a creep related modification factor be used because the geotextile can exhibit creep.

Equation (1) uses modification factors to the base puncture resistance of the material to calculate the amount of geotextile protection that is necessary to prevent puncture. Suggested values of the modification factors are presented in Koerner (1997) and are shown in Table 1. One modification factor for critical cone height is not included in Table 1 because data on PVC geomembranes were not available prior to Stark et al. (2008). Based on the ASTM D5514 (1999) puncture tests conducted by Stark et al. (2008), which are summarized in Figure 1, PVC geomembranes exhibit a higher puncture resistance after the maximum particle size falls below the critical cone height. Stark et al. (2008) suggest the following values for MF_{CCH}:

- If the critical cone height is greater than the maximum particle size, MF_{CCH} =0.1.
- If the critical cone height is less than or equal to the maximum particle size, MF_{CCH} =1.0.

If MF_{CCH} is 0.1, that means the geomembrane should not puncture because the maximum particle size is less than the CCH. Using a value of 0.1 results in a higher value of p'_{allow} because MF_{CCH} is in the denominator of Equation (1). Conversely, if MF_{CCH} is unity that means the geomembrane may puncture because the maximum particle size is greater than the critical cone height. Using a value of unity results in a lower value of p'_{allow} which may result in the need for a cushion geotextile.

The use of MF_{CCH} equal to 0.1 or 1.0 is extreme and doesn't reflect the adaptability of a flexible geomembrane, such as a PVC geomembrane to a range of particle sizes. Thus, there is no benefit of the geomembrane having a large critical cone height and being flexible to resist even large particle sizes that are less than the critical cone height. A more sensitive approach to MF_{CCH} was sought and is presented herein. Figure 2 plots MF_{CCH} as a function of particle size for different critical cone heights, where the minimum MF_{CCH} is 0.1. If a cushion geotextile is used, the value of MF_{CCH} should be set to unity regardless of the protrusion height in the field. Figure 2 shows that MF_{CCH} can now vary between 0.1 and 1.0 depending on the cone height. This results in a more logical estimate of p'_{allow}.

A base puncture resistance of 80 kPa is used to represent the strength of unreinforced PVC geomembranes such that the allowable pressure that can be applied without puncturing a 0.75 mm PVC geomembrane (see Figure 1) is given by the following expression:

$$P_{allow} = 450 \frac{M_A}{H^2} \geq 80 kPa \qquad (2)$$

3.1 Puncture Protection Design Example

This example is based on an example presented in Koerner (1997). Given a 0.75 mm thick PVC geomembrane under a layer of AASHTO No. 57 angular drainage stone (maximum size of 25 to 38 mm) and 50 m of solid waste (unit weight of 11.8 kN/m^3), determine the required mass per unit area of a protection geotextile that will provide a global factor of safety of 3.0. Assume that the subgrade, e.g., compacted low permeability soil, was prepared such that the effect of any isolated protrusion underneath the geomembrane is insignificant in comparison with the effect of the overlying drainage stone.

Using Table 1 and assuming that the effective protrusion height (16 mm) is equal to half the maximum stone size ((25 + 38) / 2 = 32 mm), the following data is used for the puncture evaluation for the 0.75 mm thick PVC geomembrane:

- effective protrusion height, H = 16 mm;
- Critical cone height for 0.75 mm thick PVC geomembrane = 80 mm (see Figure 1)
- modification factors: (see Table 1)
  - protrusion shape, MF_S =1.0
  - packing density, MF_{PD} = 0.5
  - soil arching, MF_A = 1.0
  - critical cone height, MF_{CCH} = 0.22, from Figure 2, with CCH=80 mm and maximum particle size=32 mm
- partial factors of safety: (see Table 1)
  - creep, FS_{CR} = a function of M_A (to be determined)
  - chemical and biological degradation, FS_{CBD} = 1.5;

- global factor of safety = 3.0; and
- mass per unit area of the available geotextiles varies between 130 to 1500 g/m^2.

The allowable pressure on the geomembrane can be computed as follows:

$$P'_{allow} = FS * P_{reqd} = 3.0 * 50m * 11.8kN/m^3 = 1770kPa$$

This value is expressed in terms of the unknown mass per unit area of the geotextile and partial factor of safety against creep as follows:

$$p'_{allow} = \left(450\frac{M_A}{H^2}\right)\left(\frac{1}{MF_S \times MF_{PD} \times MF_A \times MF_{CCH}}\right)\left(\frac{1}{FS_{CR} \times FS_{CBD}}\right)$$

rearranging and substituting:

$$M_A = \frac{\left(p'_{allow}\right)\left(H^2\right)\left(MF_S \times MF_{PD} \times MF_A \times MF_{CCH}\right)\left(FS_{CR} \times FS_{CBD}\right)}{450}$$

$$M_A = \frac{(1770kPa)(16mm)^2(1.0 * 0.5 * 1.0 * 0.22)(FS_{CR} * 1.5)}{450}$$

$$M_A = 166 * FS_{CR}$$

It is clear that a geotextile with a mass per unit area greater than 170 g/m^2 is required. Using a creep factor of safety of 1.3 from Table 1, the resulting required mass per unit area of the geotextile is:

$$M_A = 166 * 1.3 = 216g/m^2$$

A cushion geotextile with a mass per unit area of 216 g/m^2 or greater is required for 50 m of solid waste (unit weight of 11.8 kN/m^3) being placed on top of the angular drainage stone. For comparison purposes, a 500 g/m^2, nonwoven geotextile or twice as much mass is required for a 1.5 mm thick HDPE geomembrane (Koerner 1997).

4 CONCLUSIONS

The purpose of this technical note is to present a design procedure for estimating the puncture protection required for PVC geomembranes. To capture the flexible nature of PVC geomembranes new values of MF_{CCH} were developed that reflect the behavior of PVC geomembranes against various particle sizes. This allows the value of MF_{CCH} to vary from 0.1 to 1.0 instead of being either 0.1 or 1.0. Equation (1) can be used to estimate the allowable applied pressure or the mass per unit area of a cushion geotextile for a maximum particle size.

NOTATION

p'_{allow}	allowable pressure on the geomembrane (kPa)
M_A	mass per unit area of cushion geotextile (g/m^2)
H	effective protrusion height (mm)
MF_S	modification factor for protrusion shape
MF_{PD}	modification factor for packing density
MF_A	modification factor for soil arching
MF_{CCH}	modification factor for critical cone height
FS	factor of safety
FS_{CR}	factor of safety for creep
FS_{CBD}	factor of safety for chemical and biological degradation
P_{allow}	allowable pressure (kPa)

ABBREVIATIONS

PVC	polyvinyl chloride
CCH	critical cone height
HDPE	high-density polyethylene
CSPE-R	chlorosulfonated polyethylene
VLDPE	very low density polyethylene

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Table Caption:

Table 1. Modification and reduction factors for geomembrane protection design using nonwoven needle-punched geotextiles (Koerner 1997)

Figure Captions:

Figure 1. Puncture pressure versus truncated cone height for various geomembranes

Figure 2. MF_{CCH} modification factor as a function of maximum particle size

Table 1. Modification and reduction factors for geomembrane protection design using nonwoven needle-punched geotextiles (Koerner 1997)

Modification Factors

MF_S		MF_{PD}		MF_A	
Angular	1.0	Isolated	1.0	Hydrostatic	1.0
Subrounded	0.5	Dense, 38 mm	0.83	Geostatic, shallow	0.75
Rounded	0.25	Dense, 25 mm	0.67	Geostatic, mod.	0.50
		Dense, 12 mm	0.50	Geostatic, deep	0.25

Reduction Factors

		RF_{CR}			
			Protrusion (mm)		
RF_{CBD}		Mass per unit area (g/m^2)	38	25	12
Mild leachate	1.1	Geomembrane alone	N/R	N/R	N/R
Moderate leachate	1.3	270	N/R	N/R	>1.5
Harsh leachate	1.5	550	N/R	1.5	1.3
		1100	1.3	1.2	1.1
		>1100	≈ 1.2	≈ 1.1	≈ 1.0

N/R = Not recommended

Figure 1. Puncture pressure versus truncated cone height for various geomembranes

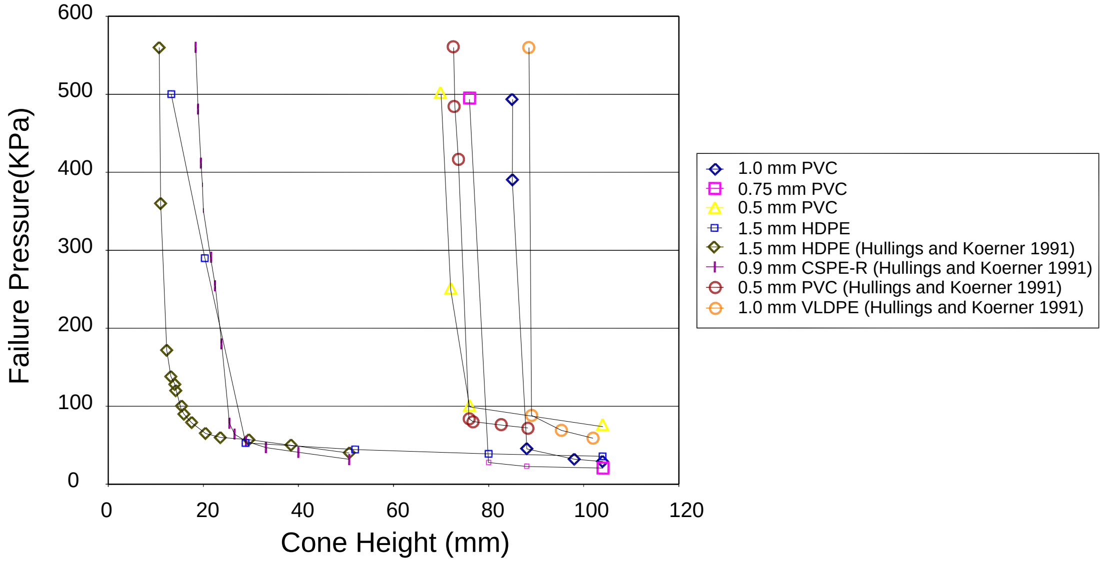

Figure 2. MF_{CCH} modification factor as a function of maximum particle size