Improving the Stability by Using Geosynthetics in Sealing Systems

C. Scheu, F. Saathoff
Naue Fasertechnik GmbH & Co. KG, Luebbecke, Germany

D. Bishop
Naue Fasertechnik GmbH & Co. KG, Lemfoerde, Germany

ABSTRACT: With regard to the stability of the slope, the construction of sealing systems for landfills on inclined areas requires an exact knowledge of the short- and long-term behaviour of geosynthetics as well as the interaction of the individual components and the system as a whole. The construction of sealing systems with steep slopes is of great interest for economical reasons. When the inclination of a slope is increased from e.g. 1 : 4 (vertical : horizontal) to 1 : 2.5 the storage capacity is raised by approx. 60 %. The friction behaviour of the contact shear surfaces together with the maximum admissible stress on geosynthetic layers is vitally important. It is the purpose of reinforcement layers with the lining system to take up and conduct tensile forces both for short- and long-term periods. This paper presents stability calculations which have proven their effectiveness in practice.

1 INTRODUCTION

Multilayer sealing systems in slopes are installed both in base and capping seals for landfill sealing systems. In cappings of landfills or contaminated soils geosynthetics such as geosynthetic clay liners (GCLs) (Heerten and Scheu, 1990, and Heerten, Saathoff, Scheu, and Maubeuge, 1994), drainage mats and reinforcement grids take over a multitude of functions:

- leachate and gas barrier (Heerten, 1992),
- drainage of leachates and gas (Heerten, 1992) and
- long-term tensile forces (Scheu and Jas, 1992).

The combined capping of contaminated soils or industrial waste with drainage mats for the gas collection, GCLs for sealing against the rainwater and gas escape, drainage mats for the drainage of leachates, geogrids for reinforcement and soil cover layers are state-of-the-art and entail both a reduction of the thickness and a decisive advantage regarding the steeper construction of a slope.

For base sealing systems the so-called combinated sealing system is generally accepted which consists of a mineral sealing layer and a geomembrane. Since waste heights of 40 m are quite frequent, extremely high normal stresses have to be expected. This can then result in very high shear stresses. With regard to this the installation of geomembranes with smooth surfaces has to be preferred in base sealing systems.

These principles lead to opposite conditions: on the one hand a limiting of the transmission of shearing forces to the geomembrane and on the other hand a steep construction of sealing systems with smooth geomembranes.

When the friction angles between the geotextile protection layer (the installation of mineral protection layers on a smooth geomembrane is extremely difficult or even impossible on steeper slopes) and the geomembrane with a smooth surface amounts to approx. 10° (friction coefficient = 0.18) the use of reinforcement layers is absolutely necessary. Similar conditions can be found in horizontal systems: The process of installing drainage cover layers in the short term leads to high spreading forces which have to be absorbed by the reinforcing layers.

The following statements for the dimensioning of reinforcement layers in slopes considers the installation and the final state conditions. Furtheron, the construction of anchor trenches, the characteristic tensile strength of the reinforcement and the occuring deformations in the whole system are commented upon.

2 LANDFILL SEALING SYSTEMS ON SLOPES

The standard design of an inclined capping system for landfills consists at least of a sealing system (mineral sealing layer, geomembrane or a combination of these elements), a drainage layer (mineral drainage or drainage mats), reinforcement layers (geogrids) and soil cover layers.

The thickness of the soil cover layer as well as the length and inclination of the slope have a decisive influence on the necessary tensile strength of the reinforcement element. With regard to the principle, the stability of base sealing systems may be examined in a similar way.

2.1 Dimensioning of the Final State

The basis for this consideration is a steep slope with an inclination angle β (°) and a height H (m) (Fig. 1). Thus, the length of the embankment is defined with $L = H / \sin \beta$.

If a standard design (subgrade/sealing layer (GCL) - drainage layer (drainage mat) - reinforcement layer (geogrid) - cover soil) is assumed, a displacement between sealing layer and drainage mat has to be expected. This surface can be considered as a critical shear surface with the related friction coeffecient tan ψ. An exact determination of the shear parameters in this plane is very important for the dimensioning. Here, laboratory tests using a large shear box and the site specific products need to be carried out.

If it is assumed that a flow force e.g. from heavy rain, with an average level of 10 cm occurs in the cover layer, the change in the unit weight of the soil is neglected and an hydraulic gradient of $i = \sin \beta$ exists, the resulting flow force, F, is given by:

$$F = \gamma_W \bullet \sin \beta \bullet 0.10 \bullet l = l \bullet \sin \beta \qquad (1)$$

with γ_W as unit weight of water (10 kN/m^3), l as length of the slope and β as slope inclination.

The load of the cover layer per meter depth (Figs 1-2) can be calculated with:

$$P = \gamma \bullet l \bullet d / \cos \beta \qquad (2)$$

with γ as unit weight of cover soil, d as thickness of the cover layer.

The shearing stress T in downward direction is

$$T = P \bullet \sin \beta = \gamma \bullet l \bullet d \bullet \tan \beta \qquad (3)$$

and the related normal stress N is

$$N = P \bullet \cos \beta = \gamma \bullet l \bullet d \qquad (4)$$

The extreme shear tension T_f in the critical shear plane can be described by a failure condition according to Mohr-Coulomb

$$T_f = a + N \bullet \tan \psi \qquad (5)$$

a being the adhasion which is not considered for safety reasons (a = 0).

The examination of test planes parallel to the slope (sliding surfaces) is sufficient for the proof of the stability against sliding. For the adverse case (sliding surface geomembrane - protection layer or drainage mat) the safety factor η is deduced by comparing the existing shearing forces with the shearing force which can be maximally absorbed (Günther and Foik, 1990):

$$\eta = \frac{T_f + T_G}{F + T} \qquad (6)$$

with T_G as tensile strength of the geogrid.

According to DIN 4084 the safety factor η = 1.3 and η = 1.2 has to be observed when proving the stability against sliding for the cases 1 (long-term) and 2 (short-

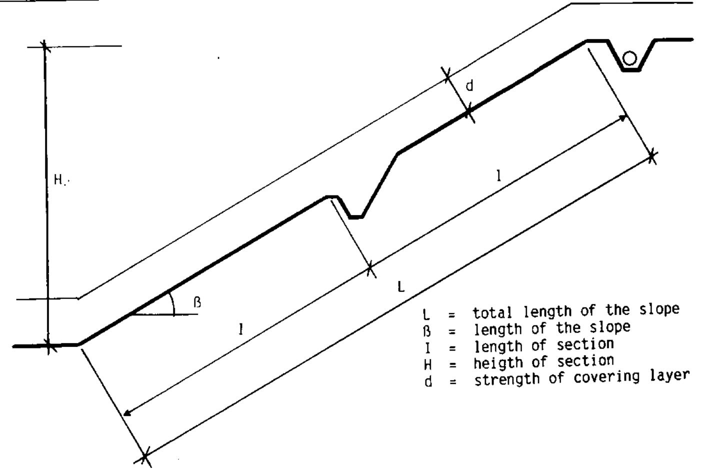

Figure 1: Landfill base slope (Scheu and Jas, 1992)

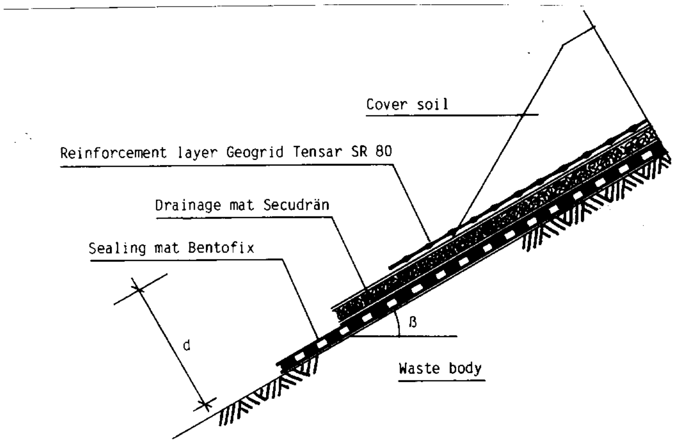

Figure 2: Landfill covering (Scheu and Jas, 1992)

term or construction stage). If the equations (1) to (5) are put into (6), the following relation will result:

$$\eta = \frac{(\gamma \bullet l \bullet d \bullet \tan \psi + T_G)}{(l \bullet \sin \beta + \gamma \bullet l \bullet d \bullet \tan \beta)} \qquad (7)$$

or summarized

$$T_G = \gamma \bullet l \bullet d \bullet [\eta \bullet (\sin \beta / (\gamma \bullet d) + \tan \beta) - \tan \psi] \qquad (8)$$

2.2 Dimensioning for the Construction State

During construction higher short-term loads will occur due to for example construction equipment installing the cover layers or additional cover material being stored on the slope; these will have to be considered as well. In this case the limiting condition with a total safety factor η is

$$\eta = \frac{(\gamma \bullet l \bullet d + A \bullet \cos \beta) \bullet \tan \psi + T_G}{(\gamma \bullet l \bullet d \bullet \tan \beta + A \bullet \sin \beta)} \qquad (9)$$

with A as load from additional cover material and construction equipment. The solution of the equation for T_G results in:

$$T_G = \gamma \bullet l \bullet d \bullet (\eta \bullet \tan\beta - \tan\psi) + K \quad (10)$$

where $K = A \bullet \sin\beta \bullet (\eta - \tan\psi / \tan\beta)$.

3 EXAMPLE OF A LANDFILL COVERING

During the reconstruction of a landfill for residues it was necessary to design a sealing system on a slope with a total length of approx. 34 m and an inclination of 1 : 2 ($\beta = 26°$). The following composition of the sealing system was chosen (from bottom to top):

- subgrade,
- nonwoven protection layer with a mass per unit area of 1000 g/m^2,
- geomembrane,
- drainage mat,
- geogrid and
- 30 cm cover soil.

The slope is divided into three sections (length of the section 11.5 m). Thus the reinforcement is anchored to the slope at three points - at 2 intermediate berms and at the crest (Fig. 3).

3.1 Loading in the Final State

If equation (8) is applied and if a unit weight of $\gamma = 18$ kN/m^3, a safety factor of 1.3 in the final state and a

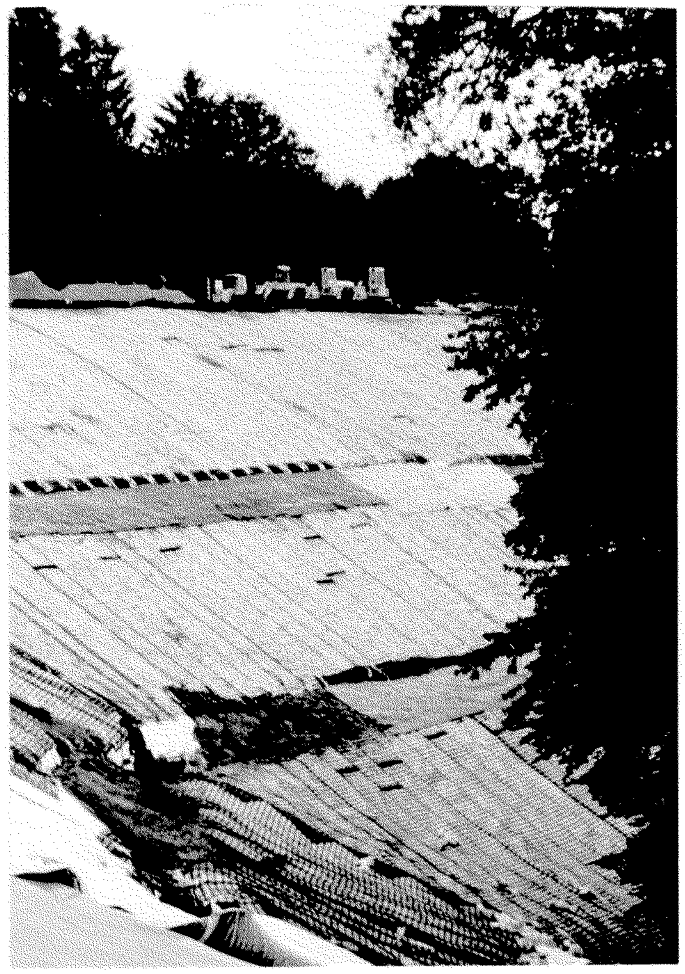

Figure 3 Landfill Covering with an Inclination of 26° (Scheu and Jas, 1992)

decisive potential shear plane between geomembrane and drainage mat with a friction angle of $\psi = 12°$ are taken into consideration, then the characteristic tensile strength T_G has to be at least:

$T_G = 32.7$ kN/m

3.2 Construction State

For the construction state it is assumed that the load results from a bulldozer (130 kPa and a width of 3 m resulting in 43 kN/m) and from cover material (200 kPa and a width of 5 m resulting in 40 kN/m). According to equation (10) the limiting condition is

$T_G = 44.5$ kN/m

3.3 Anchor Trench at the Slope Crest

The anchor trench at the embankment crest can be dimensioned by applying the following equation (Fig. 4):

$$T_G \bullet \eta = i \sum \gamma_i \bullet h_i \bullet l_i \bullet \tan\phi_{ui}$$

$$1.16 \bullet h^2 + (2.3 \bullet d + 0.5) \bullet h + [(l + 0.5) \bullet d - \eta \bullet T_G / 0.876 \bullet \gamma) \geq 0$$

If $d = 0.5$ m, $l_1 = 1$ m, $T_G = 33$ kN/m, $\eta = 1.3$ and $\gamma = 18$ kN/m^3 a minimum thickness of $h = 80$ cm is achieved.

When checking the construction state ($T_G = 45$ kN/m and $\eta = 1.1$) it is necessary to increase the covering height to $d = 0.7$ m in order to achieve the required safety.

3.4 Dimensioning of the Embankment Berm

The geometry of Fig. 3 result in a minimum depth of the trench of $h = 0.5$ m in the final state ($\eta = 1.3$) provided that $d = 0.3$ m, $T_G = 33$ kN/m and $\gamma = 18$ kN/m^3.

According to the calculation of the construction state ($T_G = 45$ kN/m and $\eta = 1.1$) the depth of the trench increases to $h = 0.6$ m.

3.5 Occuring Deformations

The determination of the deformations which occur is based on a total deformation of $\varepsilon_T = 10$ % of the reinforcement. This means an average deformation of $\varepsilon_A = 5$ %. If the length of the reinforcement amounts to 11.5 m, a total deformation of 0.58 m has to be expected. This 0.58 m develops so:

$0.8 \bullet 0.58 = 0.46$ m during the loading,
$0.1 \bullet 0.58 = 0.06$ m during the installation (200 hours) and
$0.1 \bullet 0.58 = 0.06$ m during the remaining life-time.

For a realistic assessment of the deformations of the length of the reinforcement the considered safety factors would have to be neglected (e.g. $\gamma = 16$ kN/m^3, $\eta = 1.0$, $\psi = 14°$). Thus, the real tensile strength of the geogrids is

Figure 4 Anchoring of geotextiles at the slope crest (Scheu and Jas, 1992)

calculated according to equation (8)

$T_G = 15.8$ kN/m

and associated with this a deformation of

$$\frac{15.8}{33.0} \bullet 10\,\% = 4.8\,\%$$

for Geogrid *Tensar® SR 80*. The average elongation amounts to $\varepsilon_A = 2.4\,\%$ or an extension of

$$\frac{2.4}{100} \bullet 11.5 \bullet = 0.28 \text{ m}$$

from which occur

0.8 • 0.28 = 0.22 m at the loading,
0.1 • 0.28 = 0.03 m during the installation and
0.1 • 0.28 = 0.03 m during the life-time

of the construction. The extension of 3 cm surely will not cause any damage.

4 RECOMMENDATIONS OF INSTALLATION

The following factors have to be considerd when a sealing system is installed on steep slopes:

- in case of anchor trenches in the slope or the slope crest the transfer of the loads from the reinforcement to the ground must be carefully considered,
- information on filling and pre-filling material to be used must be known,
- construction equipment used,
- instructions regarding the direction of the filling process,
- if possible construction vehicles should not drive in downward direction of the slope,
- tension-proof connection of the geogrids by means of bodkins are necessary,
- when different types of geogrids are used the strongest grid has to be installed in the upper part of the slope and
- safety regulations have to be observed.

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