*The Evolution of Geotech - 25 Years of Innovation – Hammah et al. (Eds)*


# Assessment of asperities geometry influence on MSW landfill critical interface side-slope stability using probabilistic analysis

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ABSTRACT: Geomembrane asperities are surface protrusions which distinguish smooth geomembranes from textured geomembranes. Asperities possess geometrical features such as height and concentration and are hypothesised to develop high interface shear strength, resist sliding and increases stability. To date, many textured-geomembranes with different asperity geometries have been manufactured and used in landfill linings together with geosynthetics like geotextiles. Previous studies have considered the effects of asperity geometries to geomembrane/geotextile interface shear characteristics. However, limited studies have considered the effects of asperity height and concentration on the landfill side-slope liner factor of safety (FoS) using the geomem- brane/geotextile critical interface as the point of reference. Thus, this study was aimed at investi- gating the influence of asperity geometries on liner stability. This study utilized experimental results from direct shear test (i.e. friction angle and adhesion) and performed probabilistic stability analysis using SLIDE2. Available results indicated that FoS increased as both asperity concen- tration and height increased. However, asperity-height increased beyond 1.2 mm mobilized FoS reduction. Therefore, obtaining an optimised liner stability factor is hinged on selecting the ap- propriate geomembrane asperity geometry at the critical geomembrane/geotextile interface.

## 1 INTRODUCTION

Presently, geosynthetics incorporation into municipal solid waste (MSW) landfill liner con- struc- tion is widely accepted, particularly in South Africa. The geosynthetics function of interest may include separation, filtration, drainage, barrier, protection, and reinforcement function. It should be noted that this study focuses on functions such as barrier and protection where geosynthetics surface features (asperities) have significant effects on a typical landfill liner design life. The placement of geosynthetics with other geomaterials often results in interface interaction with dis- tinct shear characteristics which is necessary to ensure the stability of the side-slope liner. In a landfill liner, possible single geosynthetics interface include geomembrane/geosynthetic clay liner (GMB/GCL), geosynthetic clay liner/compacted clay liner (GCL/CCL), geomembrane/geo- textile (GMB/GTX), and geotextile/geocomposite drain (GTX/GCD) (Bhatia & Kasturi, 1996). However, studies by Bergado et al., (2006); Xuede (2008); Bacas et al., (2015) identified GMB/GTX interface as an interface with lower frictional resistance and shear strength (i.e. “crit- ical interface”). Thus, this critical interface was the focus of this study.

The mobilization of shear strength at the critical interface (GMB/GTX) is highly dependent on surface features such as roughness and asperities. In some of the reviewed design problem

DOI: 10.1201/9781003188339-26

in literature, it has been assumed that shear mobilization is directly proportional to the measured asperity height. However, this assumption was contradicted by Blond & Elie (2006) where they concluded that, for a given range of asperity measurement, there exists an intermediate asperity property beyond which there is little or no increase to the recorded shear parameter. The assumed mobilization of shear strength dependent on asperity properties would have important implica- tions on design, particularly at the side-slope and during unfavourable environmental conditions (increased leachate). Incorrect assumptions of the shear characteristics might lead to inadequate design and eventually slope failure. Therefore, this study investigated the effect of asperities on MSW landfill critical interface side-slope stability using probabilistic analysis.

## 2 PROBLEM DESCRIPTION

### 2.1 *Overview*

In this paper, an assessment study was carried out on geosynthetics landfill liner system using finite element method (FEM) based software SLIDE2 (Rocscience) to determine the variation of peak factor of safety (FoS) as a function of altered asperity measurement. The slope geometry used in this study and illustrated in Figure 1 was adopted from Qian & Koerner (2004). The slope inclination was modified from 3H:1V to 1H:1V as the latter is more critical and typifies unfa- vourable condition. To investigate the effects of asperity geometry on the shear strength mobilized at the geomembrane/geotextile interface, asperity height and concentration were varied.

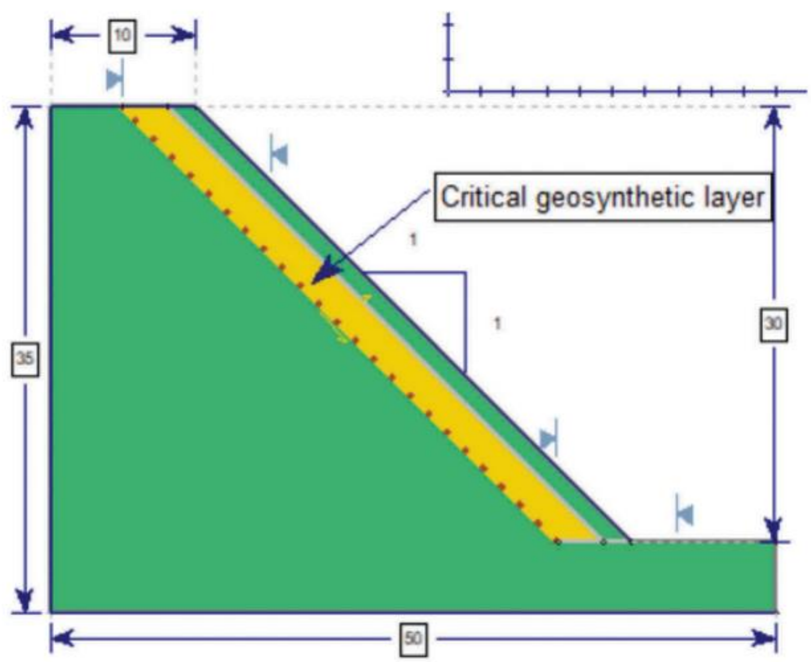


Figure 1. Slope geometry used in the study.

### 2.2 *Slope geometry and properties*

The selected unit weight, apparent cohesion, friction angle, Poisson's ratio, and elastic modulus of the soil used were 18 kN/m3, 30 kPa, 15°, 0.3, and 20, respectively (Qian & Koerner, 2004). A firm stiff clay layer has been assumed for the foundation soil to minimize the probability of failure surface development at the founding soil. The geosynthetic liners were designed to account for anchorage length.

## 2.3 *Numerical modelling of slope*

SLIDE2, a 2-D elastoplastic finite element stress analysis program was used for the modelling of this investigation. SLIDE2 is a dynamic finite element program with efficiency in slope stability analysis. Previous researchers have used SLIDE2 for stability analysis of conventional slope (with soil as a primary material) (Berisavljević et al., 2015; Pillay, 2017). An elastoplastic constitutive model available in the program was used for analyzing the slope. The GLE/Morgenstern-Price method of analysis was selected because it satisfies all conditions of equilibrium and includes reasonable assumptions (Aswathi et al., 2017; Patuti et al., 2019). Also, the circular grid search option was selected as the preferred surface option. The geomembrane/geotextile (GMB/GTX) interface was selected as the critical interface (with least resistance) and was represented in the model as the weak layer material and critical geosynthetic layer.

In the constitutive modelling, peak shear characteristics (friction angle and apparent adhesion) were taken as the weak and geosynthetic layer material strength and were described by the Mohr- Coulomb model. It should be noted that the peak shear parameters were obtained from the direct interface shear test conducted between geomembrane and geotextile in accordance to ASTM D5321 (2014) and using Shear Trac-III – a large direct shear device built by Geocomp Corpora- tion Company. Shear Trac-III top box had a cross-sectional area of 305 mm by 305 mm and a thickness of 100 mm while the bottom shear box had dimensions of 460 mm x 355 mm x 100 mm. To test the shear strength of geomembrane and geotextile interfaces, the geomembrane was affixed to the lower box while the geotextile was attached to the top box. The tests were conducted at normal stresses of 25, 50, 100, 200, and 400 kPa and together with the resulting shear stress were utilized to develop the failure envelope.

Though either polypropylene (GTX-PP) or polyester (GTX-PET) geotextile could be interfaced against the geomembrane (GMB), this study focused on examining the interaction between GMB & GTX-PET interfaces only. This is because Adeleke et al. (2019) and Adeleke (2020) reported that GTX-PET interfaces exhibit greater shear characteristics than GTX-PP interfaces. The unit weight of the GMB/GTX interface required in SLIDE2 was determined by considering the unit area of the geotextile. This is because geotextile unit area (400 $g/m^2$) was less than ge- omembrane unit area (9400 $g/m^{2,}$ converted from 0.94 g/cc formulated density). GTX-PET re- ported unit area of 400 $g/m^2$ was converted to $kN/m^3$ by factoring in acceleration due to gravity (g) and per meter run length. Therefore, 4 $kN/m^3$ was estimated for the GMB/ GTX interface. Furthermore, the weak layer friction angle and apparent cohesion were continuously altered as the geomembrane surface asperities changed, as shown in Table 1. Each geomembrane was dis- tinguished from another by adding an alphanumeric character to the label such as S, T1, T2, . . ., T7, where S and T represent smooth and textured geomembrane.

Table 1. Geosynthetic interface asperity and shear characteristics

| Interface label | Asperity properties | | Shear charactersitstic | |
|---|---|---|---|---|
| | Height (mm) | Density (knobs/area*) | Friction (°) | Adhesion (kPa) |
| GMB – S/GTX | 0.0 | 0 | 16.8 | 0.8 |
| GMB – T1/GTX | 0.7 | 332 | 27.5 | 9.1 |
| GMB – T2/GTX | 0.7 | 663 | 30.3 | 17.2 |
| GMB – T4/GTX | 0.9 | 337 | 28.3 | 6.5 |
| GMB – T5/GTX | 1.2 | 306 | 35.2 | 11.7 |
| GMB – T6/GTX | 1.8 | 211 | 32.1 | 13.7 |
| GMB – T7/GTX | 2.0 | 217 | 31.4 | 13.9 |

* Area = 10000 $mm^2$.

## 3 RESULTS AND DISCUSSION

Although a conventional limit equilibrium method (LEM) recommended by Rouncivell (2007), ASTM D5321 (2014), and Buthelezi (2017) could have been utilized in this study, a modified approach tailored to SLIDE2 was selected instead. This was necessary to explore the added fea- tures of the Rocscience software package. Also, the conventional LEM approach is often limited to translational failure, whereas other forms of failure such as rotational, foundational, and com- posite failures are likely to occur in a landfill design life. A typical model for the slope, surround- ing soil, and critical geosynthetic interface layer is presented in Figure 2.

### 3.1 *Effect of asperity height on FoS*

As landfills are subjected to lower and higher confining stresses at different construction stages, and various slope positions of the landfill, a linear and/or non-linear Mohr-Coulomb failure en- velope is more appropriate to characterize the mode of failure of the liner (Sikwanda 2018). There- fore, in this section, the results obtained by computing a Mohr-Coulomb failure envelope on dif- ferent geomembrane/geotextile interfaces, depending on asperity height variation, were utilized. Additionally, to establish the degree of variation of the mobilized FoS from the smooth geomem- brane/geotextile interface, the percentage difference (PD) between the obtained FoS and the con- trol value was calculated – where the smooth geomembrane interface acted as the "control".

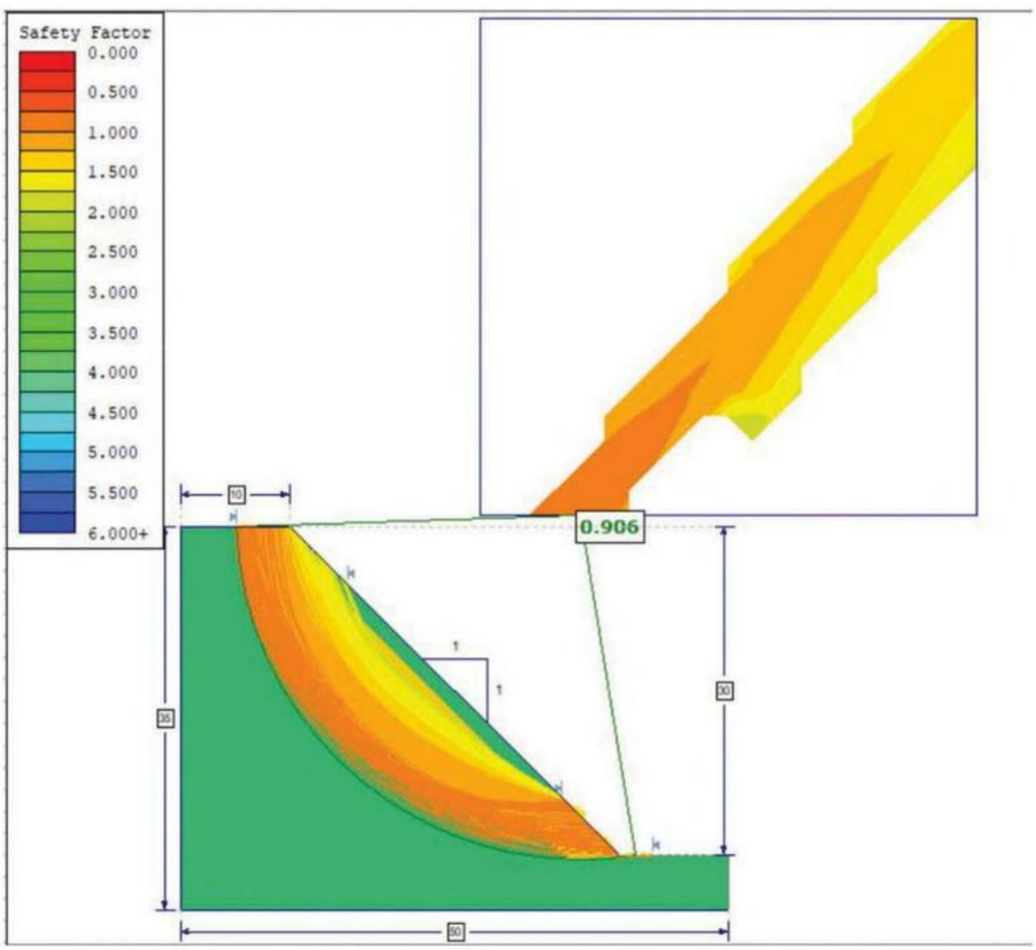


Figure 2. The numerical model of the slope prepared in SLIDE2 (Rocscience).

Considering GMB-T1/GTX relative to the smooth interface, it was evident that the inclusion of asperities produced a 69.5 % increase in the slope stability factor of safety (FoS). As regards the gradual increase in asperity height (0.70 mm, 0.85 mm, & 1.20 mm) at an average constant asperity concentration of 325 knobs/10000 $mm^2$ for GMB-T1/GTX, GMB-T4/GTX, & GMB- T5/GTX, it was observed that a corresponding increase in FoS was recorded, particularly at 1.20 mm asperity height (see Table 2). Though GMB-T4/GTX exhibited a slight reduction in the com- puted FoS, the reduction was attributed to other material properties such as roughness and rigidity, which were beyond the scope of this investigation.

Furthermore, it was identified that a gradual increase in asperity height for heavily textured geomembranes such as GMB-T6/GTX & GMB-T7/GTX resulted in no corresponding FoS im- provement. An apparent reason for the absence of a corresponding increase in FoS at high asperity height could be related to the mobilization of optimal hook and loop interaction between the as- perities and geotextile fibres. In summary, the presence of asperity height triggered a greater pro- pensity for slope stability but asperity height increase in heavily textured interface produced no increment to the safety factor.

Table 2. Tested geomembrane asperity and corresponding shear characteristics.

| Interface label | FoS | PD* |
|---|---|---|
| GMB – S/GTX | 0.528 | 0 |
| GMB – T1/GTX | 0.895 | 69.5 |
| GMB – T2/GTX | 0.906 | 71.6 |
| GMB – T4/GTX | 0.893 | 69.1 |
| GMB – T5/GTX | 0.906 | 71.6 |
| GMB – T6/GTX | 0.905 | 71.4 |
| GMB – T7/GTX | 0.905 | 71.4 |

* PD = Percentage difference relative to GMB-S/GTX.

### 3.2 *Effect of asperity density/concentration on FoS*

With the obtained data on asperity concentration variation, it was observed that the doubling of asperity concentration in (GMB-T2/GTX) produced the greatest improvement (71.6 %) on slope stability safety factor when compared with the smooth geosynthetic interface. This improvement corresponds to the optimal FoS as asperity height was varied. Besides the increase in friction angle, apparent cohesion was identified as the primary contributor to the improvement observed at GMB-T2/GTX interface. The increased cohesion was attributed to the large surface area pro- vided by asperities through which geomembranes/geotextiles interaction were mobilized.

## 4 CONCLUSIONS

A numerical analysis was performed to assess the shear stress mobilization within the side-slope of an MSW landfill side-slope. The following conclusion can be drawn from this study.

Peak shear strength mobilized in the "weak and geosynthetic layer" of a landfill side-slope is dependent on the individual constituent of the layer, surface features, asperity height, and asperity concentration. Also, depending on the design approach, the failure surface was slightly affected by the alteration in the asperity parameter. Furthermore, an increase in asperity height and con- centration exhibited a corresponding increase in computed FoS. While an increase in asperity height of heavily textured interface resulted in no FoS improvement.

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