Civil Mine & Quarry Geotechnics Pty Ltd
[redacted]

Dardanup Landfill Slope Stability Assessment

Date	22 April 2025
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Document Number	BEC0015-LET-0-0001
From	[redacted]

1. Introduction

1.1. General

Civil Mine & Quarry Geotechnics Pty Ltd (CMQ) has been requested by Bajwa Enviro Consult (BEC, the Client) to conduct a veneer stability assessment for Cleanaway's Banksia Road Landfill Facility, located in Dardanup, WA. It is understood that the Dardanup Landfill is planning to undertake Stage 2 capping, and as part of the design process, a check on the veneer stability is required to support the capping design.

1.2. Information Relied Upon

The following sources of information was relied upon for the stability assessment detailed within this letter:

- WML Consulting Engineers. (2021). Banksia Road Landfill, Dardanup - Landfill Capping Stability Assessment (WML Consulting Engineers Ref: 10060-G-R-001-Rev0), dated 29 November 2021.
- Golder Associates. (2016). Technical Studies to Support Design – Banksia Road Landfill (Golder Associates Ref: 1657096-001-R-Rev1), dated 12 August 2016.
- Stass Environmental. (2016). Groundwater Assessment for Site Expansion at Banksia Road Landfill, Dardanup, WA, dated July 2016.)

1.3. Scope of Work

The Scope of Work for this project includes the following:

- Review of the input parameters from WML Consulting Engineers (2021) and assess suitability for the purpose of this veneer stability analysis. Undertake veneer stability assessment based on the above parameters, for a 1V:3.5H slope and 180 m slope length (as nominated by BEC).
- Prepare a level letter report summarising the findings of above veneer stability assessments (this letter).

1.4. Limitations

This letter has been prepared by CMQ for the exclusive use of Bajwa Enviro Consult and Cleanaway Solid Waste and may only be relied upon by Bajwa Enviro Consult and Cleanaway Solid Waste for the purposes outlined in Section 1.2 of the letter. CMQ disclaims any responsibility to any other party in connection with this report. CMQ also excludes implied warranties and conditions, to the extent legally permissible.

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2. Background

2.1. General

The Cleanaway Dardanup Solid Waste Services (Dardanup Landfill, WA6236)) is operated by Cleanaway and is located at Lot 2, Banksia Road in Dardanup, approximately 4 km southeast of the township of Dardanup. The landfill facility is licensed to accept Category 61: liquid waste and Category 64: Class II or III putrescible landfill waste, with approved capacities of 353,000 t/year and 350,000 t/year respectively (WML, 2021). Figure 1 presents the location of the Dardanup Landfill.

CMQ understands that BEC was engaged to undertake the Stage 2 Cap design for the landfill, which requires an assessment of the veneer stability of the proposed 1V:3.5H slope.

Figure 1 The location of the Dardanup Landfill (image extracted from Google Maps)

3. Proposed Capping Design

Figure 2 presents a configuration of the proposed capping system as designed by IW Projects (IWP), which is originally documented in WML Consulting Engineer's (WML) report (2021) and subsequently adopted in the Stage 2 Cap design. The proposed cap design consists of four (4) separate layers above the waste materials and its daily cover, listed from the top to bottom as follows:

- 1.3-1.5 m thick growing medium (topsoil)
- Geocomposite drainage net with A39 top and bottom
- 1.5 mm thick Double textured LLDPE
- Geosynthetic Clay Liner (GCL)

It is noted that the growing medium will adopt the clay soil from site.

Other key elements about the cap design are listed below:

- The slope geometry of the Stage 2 capping will vary, but have a maximum slope of 1V:3.5H.
- The maximum slope length will be 180 m.

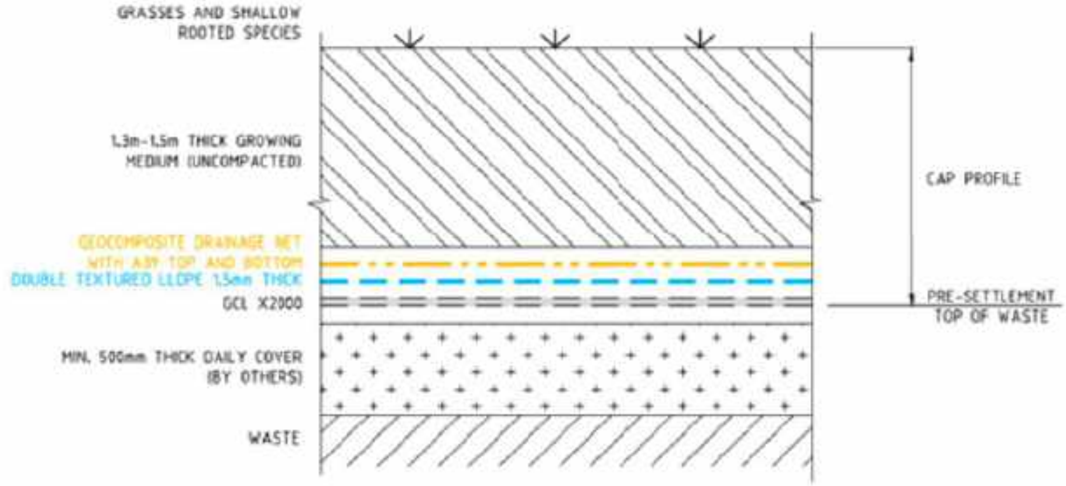

Figure 2 The proposed capping system configuration (IWP, 2021)

4. Stability Assessment Approach

4.1. Overview

The stability assessment in this technical memorandum will focus on the veneer stability analysis to determine the stability performance of the landfill cap based on the proposed capping profile. Two design scenarios, utilising the peak and residual composite failure envelopes, will be assessed separately.

4.2. Design Acceptance Criteria (DAC)

Design Acceptance Criteria (DAC) for the veneer stability analyses were based on an allowable Factor of Safety (FoS) and nominated in line with EPA expectations, as follows:

- Veneer stability
    - Peak shear strength: **FoS > 1.5**
    - Residual shear strength: **FoS > 1.2**

4.3. Material Parameters

Material parameters for the purposes of stability calculations have been sourced from the Golder Associates (2016) and WML (2021) reports and reviewed based on CMQ's experience and understanding on the materials.

The in-situ soil, which will be adopted as the growing medium for the cap design, has been sampled and tested in the Golder Associates (2016) report. The test results are summarised in the Table 1.

Table 1 The shear strength properties of the in-situ soil based on the laboratory testing (Golder Associates, 2016).

Sample	Description	Dry Density (kN/m^3)	Friction Angle (°)	Cohesion (kPa)
1	Clayey Sand – pale brown	17.5	32.6	17.4
2	Clayey Sand – pale brown	17.5	34.2	11.0
3	Clayey Sand – brown	17.4	30.5	15.1
4	Clayey Sand – brown	17.4	31.5	18.1
5	Clayey Sand – yellow/brown	17.8	22.2	48.4
6	Clayey Sand – yellow/ brown	17.8	34.4	5.0

The material properties are expected to remain valid to date. However, as the growing medium in the cap design will not be compacted, it is unlikely to exhibit the same level of cohesion as the in-situ soil. Based on the above considerations, the shear strength parameters adopted for the growing medium are presented Table 2.

Table 2 Adopted material parameters for the growing medium

Material	Unit Weight (kN/m^3)	Friction Angle (°)	Cohesion (kPa)
Growing Medium (topsoil)	17.6	30.9	5

In the WML (2021) report, the laboratory shear strength test results for each of the proposed liner interfaces of the proposed capping system were provided and summarised in Table 3. Based on CMQ's experience in similar scenarios of the capping design, the results are considered to be reasonable.

Table 3 Summary of laboratory direct shear test results on each of the interfaces in the lining system (WML, 2021)

Interface		Parameters (peak)		Parameters (residual)		Test Source
Top	Bottom	Friction Angle (°)	Adhesion (kPa)	Friction Angle (°)	Adhesion (kPa)	
Growing medium (clay soils from site)	Tri-planar geocomposite A24 top and bottom	37	0	35.9	0	Interface friction test (WML, 2021)
Tri-planar geocomposite A24 top and bottom	Textured 1.5mm LLDPE	34.4	0	18.8	1	Interface friction test (WML, 2021)
Textured 1.5mm LLDPE	GCL	29.7	8	25.7	6	Interface friction test (WML, 2021)
GCL	Clay (clay soils from site)	28.4	9	20.6	11	Interface friction test (WML, 2021)
GCL Internal		26.6	0	N/A		WML library

According to Stark & Choi (2004), the use of peak shear strength is recommended for cover systems, as back-analyses of cover failure cases indicate that peak interface strengths are typically mobilised throughout the cover system due to the limited occurrence of detrimental shear displacements. In this case, the slope gradient (15.9°) is less than the minimum friction angle of the relevant interfaces, which further reduces the likelihood of progressive failure.

However, there are situations where the residual shear strength should be adopted in the cover system design, such as when construction-induced displacements or seismically induced displacements are expected. In this case, another consideration is the maximum length of the slope, which is 180 m. This suggests that localized displacement may also pose a significant risk to the stability and serviceability of the landfill cover system.

Therefore, both peak and residual shear strengths will be adopted in the following sections and analysed separately. Based on the above considerations, different DACs have been nominated for the two scenarios in Section 4.2.

4.4. Veneer Stability

Veneer stability was calculated using the methodology outlined by Koerner & Soong (2005). The basis for the calculations is force equilibrium between the driving force, gravity, and resisting force, friction between the various cover interfaces. Figure 3 below presents the common condition of a slope of a liner material, covered by a soil layer with constant thickness. Table 4 below defines the symbols used in Figure 3.

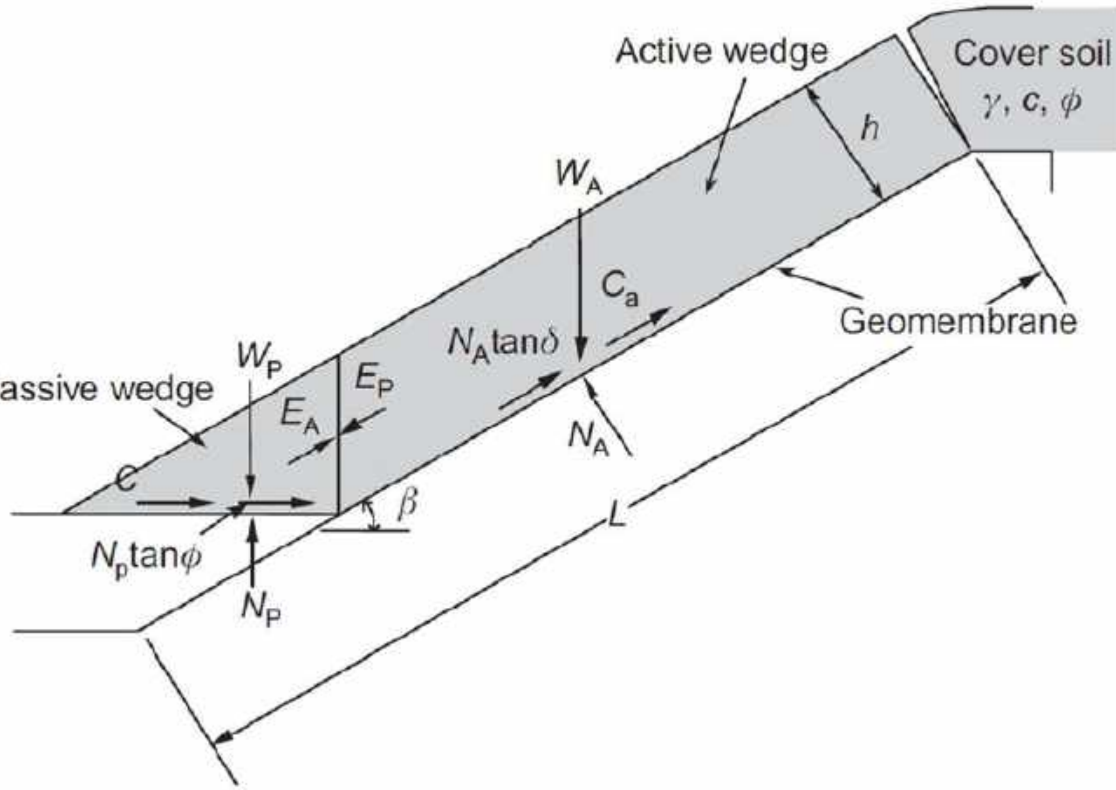

Figure 3 *Limit equilibrium forces involved in a finite length slope analysis for a uniformly thick cover soil (Koerner & Soong, 2005).*

Table 4 *Symbology descriptions (Koerner & Soong, 2005).*

Symbol	Description
W_A	Total weight of the active wedge
W_P	Total weight of the passive wedge
N_A	Effective force normal to the failure plane of the active wedge
N_P	Effective force normal to the failure plane of the passive wedge
γ	Unit weight of the cover soil
h	Thickness of the cover soil
L	Length of slope measured along the geomembrane
β	Soil slope angle beneath the geomembrane
ϕ	Friction angle of the cover soil
δ	Interface friction angle between cover soil and geomembrane
C_a	Adhesive force between active wedge cover soil and geomembrane
c_a	Adhesion between active wedge cover soil and the geomembrane
C	Cohesive force along the failure plane of the passive wedge
c	Cohesion of the cover soil
E_A	Interwedge force acting on the active wedge from the passive wedge
E_P	Interwedge force acting on the passive wedge from the active wedge

The resulting Factor of Safety from can then be obtained from the solution of the quadratic equation:

$$Factor\ of\ Safety = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

Where:

$$a = (W_A - N_A \cos\beta)\cos\beta$$

$$b = -[(W_A - N_A \cos\beta)\sin\beta \tan\varphi + (N_A \tan\delta + C_a)\sin\beta\cos\beta + \sin\beta\,(C + W_P \tan\phi)]$$

$$c = (N_A \tan\delta + C_a) sin^2\beta \tan\phi$$

5. Veneer Stability Results

CMQ has undertaken veneer stability calculations for the following five (5) interfaces at a 1V:3.5H geometry:

- Growing Medium (clay soils from site) to Tri-planar geocomposite A39 top and bottom
- Tri-planar geocomposite A39 top and bottom to Textured 1.5 mm LLDPE
- Textured 1.5 mm LLDPE to GCL
- GCL to Clay (clay soils from site)
- GCL Internal

Summarised in Table 5 and Table 6 are the calculated FoS values for the five (5) assessed capping interfaces for peak and residual shear strength respectively. The results of the analyses indicate the following:

- The calculated FoS considering the peak shear strength satisfied the nominated DAC (FoS > 1.5) for all five interfaces.
- The calculated FoS considering the residual shear strength satisfied the nominated DAC (FoS > 1.2) for all five interfaces.
- The proposed geometry is feasible based on the analyses results.

Table 5 A summary of the results of the veneer stability assessment – peak shear strength

Scenario Analysed		Slope Angle (°)	Unit Weight of Cover Soil (kN/m³)	Thickness (m)	Slope Length (m)	Friction Angle of Cover Soil (°)	Interface Friction Angle (°)	Cohesion of Soil Cover (kPa)	Adhesion of Cover Soil and Liner (kPa)	DAC	Factor of Safety
Top	Bottom										
Growing medium	Tri-planar Geocomposite	15.9	17.6	1.5	180	30.9	37	5	0	FoS > 1.5	2.70
Tri-planar Geocomposite	Textured LLDPE	15.9	17.6	1.5	180	30.9	34.4	5	0		2.46
Textured LLDPE	GCL	15.9	17.6	1.5	180	30.9	29.7	5	8		3.16
GCL	Clay	15.9	17.6	1.5	180	30.9	28.4	5	9		3.20
GCL Internal		15.9	17.6	1.5	180	30.9	26.6	5	0		1.82

Table 6 A summary of the results of the veneer stability assessment – residual shear strength

Scenario Analysed		Slope Angle (°)	Unit Weight of Cover Soil (kN/m³)	Thickness (m)	Slope Length (m)	Friction Angle of Cover Soil (°)	Interface Friction Angle (°)	Cohesion of Soil Cover (kPa)	Adhesion of Cover Soil and Liner (kPa)	DAC	Factor of Safety
Top	Bottom										
Growing medium	Tri-planar Geocomposite	15.9	17.6	1.5	180	30.9	35.9	5	0	FoS > 1.2	2.60
Tri-planar Geocomposite	Textured LLDPE	15.9	17.6	1.5	180	30.9	18.8	5	1		1.40
Textured LLDPE	GCL	15.9	17.6	1.5	180	30.9	25.7	5	6		2.58
GCL	Clay	15.9	17.6	1.5	180	30.9	20.6	5	11		2.90
GCL Internal		15.9	17.6	1.5	180	30.9	26.6	5	0		1.82

6. Conclusion

This letter details the outcomes of the veneer stability assessment of the Stage 2 Cap Geometry for Dardanup Landfill, incorporating the 1V:3.5H batter slopes with a length of 180 m in the Veneer Stability assessments. The calculated Factor of Safety (FoS) for all five interfaces, considering both peak and residual shear strengths, satisfies each of the nominated DACs (FoS > 1.5 and FoS > 1.2 respectively). Consequently, the results demonstrate that the proposed geometry is viable.

7. References

Golder Associates. (2016). Technical Studies to Support Design – Banksia Road Landfill (Golder Associates Ref: 1657096-001-R-Rev1), dated 12 August 2016.

Koerner, R. M. & Soong, T. Y. (2005). Analysis and design of veneer cover soils, *Geosynthetics International*, *12*(1), 28-49.

Stark, T.D., & Choi, H. (2004). Peak versus residual interface strengths for landfill liner and cover design. *Geosynthetics International*, 11(6), 491-498.

Stass Environmental. (2016). Groundwater Assessment for Site Expansion at Banksia Road Landfill, Dardanup, WA, dated July 2016.

WML Consulting Engineers. (2021). Banksia Road Landfill, Dardanup - Landfill Capping Stability Assessment (WML Consulting Engineers Ref: 10060-G-R-001-Rev0), dated 29 November 2021.

8. Closure

Thank you for the opportunity to complete the above technical memorandum. Please contact the undersigned should you have any further queries.

Regards,

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