PARRY'S QUARRY LANDFILL, ALLTAMI, FLINTSHIRE

Environmental Permit Application

Stability Risk Assessment

Prepared for: Mold Investments Limited

Client Ref: 416.07238.00001

SLR Ref: 416.07238.00001
Version No: 1
August 2019

BASIS OF REPORT

This document has been prepared by SLR Consulting Limited with reasonable skill, care and diligence, and taking account of the manpower, timescales and resources devoted to it by agreement with Mold Investments Limited (the Client) as part or all of the services it has been appointed by the Client to carry out. It is subject to the terms and conditions of that appointment.

SLR shall not be liable for the use of or reliance on any information, advice, recommendations and opinions in this document for any purpose by any person other than the Client. Reliance may be granted to a third party only in the event that SLR and the third party have executed a reliance agreement or collateral warranty.

Information reported herein may be based on the interpretation of public domain data collected by SLR, and/or information supplied by the Client and/or its other advisors and associates. These data have been accepted in good faith as being accurate and valid.

The copyright and intellectual property in all drawings, reports, specifications, bills of quantities, calculations and other information set out in this report remain vested in SLR unless the terms of appointment state otherwise.

This document may contain information of a specialised and/or highly technical nature and the Client is advised to seek clarification on any elements which may be unclear to it.

Information, advice, recommendations and opinions in this document should only be relied upon in the context of the whole document and any documents referenced explicitly herein and should then only be used within the context of the appointment.

CONTENTS

DOCUMENT REFERENCES

TABLES

APPENDICES

1.0 Introduction

SLR Consulting Limited (SLR) has been instructed by Mold Investments Limited (Mold) to prepare an Environmental Permit (EP) application for Parrys Quarry Landfill and an associated Waste Transfer Station (WTS), Pinfold Lane, Alltami, Flintshire (the site).

As part of the permit application, SLR has undertaken a geotechnical Stability Risk Assessment (SRA). This document describes the manner in which the assessment has been carried out and presents the overall findings of the work.

Relevant background information describing the site setting (including geological, hydrological, site monitoring data and development proposals) is detailed within the site's Environmental Setting and Installation Design (ESID)[1].

The methodology adopted for this SRA generally follows the principles outlined in the Environment Agency R&D Technical Report P-385, volumes TR1 and TR2[2] (from here on referred to as the guidance). Where additional analytical techniques have been used, these are described within the text.

1.1 Conceptual Stability Site Model

The conceptual stability site model has been developed from information contained in the ESSD[1] and review of relevant publicly available and site specific data.

The site is situated within the existing Parry's Quarry in Alltami, Flintshire and bounded by the A494 to the south, A55 to the north and Pinfold Road to the west. The National Grid Reference (NGR) for the entrance to the site is SJ 27478 66278.

The remaining land use immediately surrounding the proposed site is predominately agricultural land, with scattered residential and commercial / industrial premises. Access to the site will be via Pinfold lane.

It is proposed that the site will accept inert, non-hazardous non-biodegradable and biodegradable waste for disposal. The site will also benefit from an associated WTS; however, this operation is not assessed further in the SRA.

The installation is a former brick clay quarry covering an area of approximately 17 hectares. The site is on the edge of a valley at an elevation of 105m -110mAOD with the base of the quarry ranging from 86m – 88mAOD.

An SRA[3] was completed in 2016 as part of a previous permit application.

A review of the available data and British Geological Survey (BGS) records[4] indicate the site was underlain by superficial deposits comprising Devensian Till - Diamicton formed in the Quaternary period. This has been removed during quarry operations but remains in the surrounding area.

---

[1] SLR Consulting Ltd (2018). Parrys Quarry Landfill Environmental Permit Application Environmental Setting and Installation Design Report Ref: 416.07238.00001. Prepared on behalf of Mold Investments Limited.
[2] Environment Agency R&D Technical Report P1-385/ TR1 and TR2, 'Stability of Landfill Liner Systems', March 2003.
[3] TerraConsult (2016). Parry's Quarry Landfill Site Stability Risk Assessment. Report No 2434/R/10-SRA. Prepared on behalf of Mold Investments Limited.
[4] British Geological Survey – Geology of Britain Viewer. Available at: http://mapapps.bgs.ac.uk, accessed January 2018.

The bedrock comprises a downthrown block of Etruria Marl intersected to 32mAOD. The bedrock is described[5] as faulted blocks of sandstone, siltstone between mudstone. The wider area comprises Upper Carboniferous Westphalian Coal Measures.

The current extraction has resulted in the presence of a bund along the eastern edge of the quarry. Sections of the eastern facing external slope reach a gradient of approximately 1V:2H. The bund is constructed of site won material overlying in-situ strata and reaches a maximum height of 6m. The topographical survey indicates the bund is set back from the site boundary and the area nearest the boundary slopes upwards towards the perimeter fence. The stability of the bund was raised in comments from Natural Resources Wales. However, the bund is vegetated and has been in place long enough for the trees to reach mature height. The placement of waste will not impact the stability of the bund and it is considered to be stable in the current condition. Any minor surface cracking is shallow and attributed to the vegetation. Minor sloughing will be contained by the existing slope geometry.

Groundwater has been recorded in the base of the excavation at approximately 86.5mAOD in association with a siltstone horizon.

The quarry will be restored to a domed profile with a maximum elevation of 125mAOD.

The following sections provide further details of the principal components of the landfill development.

1.1.1 Basal Subgrade Model

The basal subgrade will be formed by the base of mineral extraction between approximately 86m – 88mAOD, sloping to the northeast in the deepest area of extraction. The basal subgrade slopes at a shallow gradient, following the base of the mineral horizon.

The current base is uneven as a result of stockpiling, access routes and extraction. Groundwater seepage has been recorded at the base of the excavation in the south of the site. As a result, the base of the quarry will be raised with site won material in order to ensure waste remains above groundwater.

1.1.2 Side Slope Subgrade Model

The side slope subgrade will be formed by the cut extraction side slopes and fill comprising site won clay. Overburden comprising glacial till is observed as being up to 2m thick in some locations with underlying mudstone of the Etruria Marl.

Extraction has left the quarry with steep sided slopes. In the main extraction area, the depth of excavation currently reaches 26m below surrounding ground level with slopes at a gradient of 1V:1.4H in the northwest. Prior to installation of the lining system site won clay will be placed against the in-situ side slopes at a maximum gradient of 1V:2.7H.

1.1.3 Basal Lining System Model

The site will benefit from full containment engineering; the lining system will comprise:

- Geological barrier a minimum of 0.5m thick constructed of clay with a permeability of $5x10^{-10}$m/s;
- Geosynthetic Clay Liner (GCL);
- Artificial sealing liner (HDPE);

---

[5] Axis (November 2016). Environmental Impact Assessment Scoping Report. Prepared on behalf of Mold Investments Ltd

- Protective geotextile (non-woven); and,
- Leachate drainage layer.

1.1.4 Side Slope Lining System Model

The side slope lining system will be composed of the same material as the basal lining system as outlined in Section 1.1.3.

1.1.5 Waste Mass Model

The site will accept non-hazardous inert or biodegradable waste for disposal. Waste will be subject to waste acceptance procedures.

The site will be filled in eight cells separated by bunds orientated approximately north to south and east to west.

1.1.6 Capping System Model

The site will be capped following placement of waste. Capping will comprise a minimum of 1m of restoration soils overlying an artificial sealing liner (LLDPE) and underlying regulation layer.

The proposed restoration contours will result in a slightly domed profile with a maximum slope gradient of approximately 1V:5H.

2.0 STABILITY RISK ASSESSMENT

Each of the six principal components of the conceptual stability site model has been considered and the various elements of that component have been assessed with regard to stability.

The principal components considered are:

- The basal subgrade.
- The side slope subgrade.
- The basal lining system.
- The side slope lining system.
- The waste.
- The capping system.

2.1 Risk Screening

Issues relating to stability and integrity for each principal component of the proposed development have been subject to a preliminary review to determine the need to undertake further detailed geotechnical analyses. The following sections present the results of this screening exercise.

2.1.1 Basal Subgrade Screening

The base of the site will be formed in in-situ bedrock with placed clay to ensure the base remains above groundwater. Each aspect of the stability and deformability of the basal subgrade identified in the Guidance is discussed in Table 2-1 below.

Table 2-1
Stability Components for Basal Subgrade

Excessive Deformation	Compressible subgrade	The basal subgrade will be formed within the in-situ bedrock or engineered low permeability clay; this is considered to be effectively incompressible under the limited stresses imposed by the replacement of excavated material with inert waste. This component does not require further consideration.
	Basal heave	Groundwater seepage has been recorded in the base of the excavation at approximately 86mAOD. Prior to installation of the lining system suitable material will be placed to prevent groundwater seepage. This component therefore does not need to be considered further.
	Cavities in subgrade	It is not considered likely that cavities will exist within the bedrock subgrade; therefore, this issue is not considered further.
Filling on Waste	Compressible waste	Not applicable.
	Cavities in waste	Not applicable.

Given the foregoing, it is considered that the basal subgrade system does not require further assessment.

2.1.2 Side Slope Subgrade Screening

The controlling factors that will affect the stability and deformability of the side slope subgrade are detailed in Table 2-2 below.

Table 2-2
Stability/Integrity Components of Side Slope Subgrade

Cut slope	Rock	Stability	Not applicable
		Cavities in subgrade	Not applicable
		Deformability	Not applicable
	Cohesive soils	Stability	Not applicable
		Deformability	Not applicable
		Time dependent stability	Not applicable.
		Groundwater	Not applicable.
	Granular soils	Stability	Not applicable.
		Deformability	Not applicable.
		Groundwater	Not applicable.
Fill Slope	Cohesive soils	Stability	Clay fill will be used to raise the base of the excavation above ground level. It will also be placed on the excavation side slopes to form a maximum gradient of 1V:2.7H. Analysis of the stability of the unconfined side slope subgrade is required.
		Time dependent stability	The lining system and waste will be placed against the clay. This component does not require further consideration.
		Groundwater	Groundwater is recorded at the base of the excavation and will not influence the side slope.
	Granular soils	Stability	Not applicable.
		Deformability	Not applicable.
		Groundwater	Not applicable.

Given the foregoing, it is considered that the side slope subgrade requires further assessment.

2.1.3 Basal Lining System Screening

The controlling factors that influence the stability and integrity of the basal lining system are given in

Table 2-3 below.

Table 2-3
Stability/Integrity Components of Basal Lining System

Mineral only	Stability and Integrity	Not applicable.
	Compressible subgrade	Not applicable.
	Cavities	Not applicable.
	Basal heave	Not applicable.
Geosynthetic / clay geological barrier	Stability and Integrity	The basal lining system will comprise an engineered lining system placed at a shallow gradient. In terms of potential for movements along the basal lining system, the development of the landfill will result in the generation of temporary waste slopes. The presence of temporary slopes may result in instability within the waste and the along basal lining system. Since this issue is largely dependent upon the geometry of the waste mass, this aspect of the stability review is covered under Section 2.1.5, Waste Mass Stability.
	Compressible subgrade	The basal subgrade will comprise in-situ bedrock or engineered low permeability clay which is considered to be effectively incompressible under the stresses imposed by the waste height proposed.
	Cavities	It is not considered likely that cavities will exist within the bedrock subgrade or basal lining system; therefore, this issue is not considered further.
	Basal heave	Groundwater seepage has been recorded in the base of the excavation at approximately 86mAOD. Prior to installation of the lining system suitable material will be placed to prevent groundwater seepage. This component therefore does not need to be considered further.

Given the foregoing, it is considered that the basal lining system does not require further assessment.

2.1.4 Side Slope Lining System Screening

The controlling factors that influence the stability and integrity of the side slope lining system are given in Table 2-4 below.

Table 2-4
Stability/Integrity Components of Side Slope Lining System

Unconfined	Mineral only	Stability	Not applicable.
		Integrity	Not applicable.
	Geosynthetic / mineral	Stability	The lining system will comprise a low permeability lining system with overlying geosynthetic. The mineral component will be placed at a maximum gradient of 1V:2.7H at a minimum thickness of 0.5m. Further assessment is required to determine the stability of the placed low permeability clay.
		Integrity	The integrity of the side slope lining system will not be compromised in the unconfined condition providing the stability assessment returns a sufficiently high factor of safety. Therefore, this aspect of the assessment does not require further consideration.
Confined	Mineral only	Stability	Not applicable.
		Integrity	Not applicable.
	Geosynthetic / mineral	Stability	If stability in the unconfined condition is satisfactory, it is clear that the stability of the side slope lining system in the confined condition will be greater due to the buttressing effect of the waste and will therefore be satisfactory. This issue is considered as being separate from the Waste Mass Analysis, which examines the influence of the confined side slope lining system on the overall stability of the waste mass. The issue of confined side slope lining system stability is therefore considered as part of the Waste Mass Analysis.
		Integrity	If the integrity in the unconfined condition is satisfactory (which may be concluded from a simple consideration of the factor of safety), it is clear that the integrity of the side slope lining system in the confined condition will be greater due to the buttressing effect of the waste and will therefore be satisfactory.

Given the foregoing, it is considered that the side slope lining system requires further assessment.

2.1.5 Waste Mass Screening

The controlling factors that influence the stability of the waste mass are presented in Table 2-5 below.

Table 2-5
Stability Components of Waste Slopes

Failure wholly in waste	Stability		Waste will be placed in phases within the void. Temporary waste slopes may be generated through progressive filling. Temporary waste slopes will require further assessment.
Failure involving lining system and waste	Mineral only	Stability	Not applicable
		Integrity	Not applicable
	Geosynthetic / Mineral	Stability	The development of the void as progressive infilling will result in the generation of a temporary waste slope in the short term. The proposed method of working is likely to generate a temporary waste slope adjacent to the side slope lining system that has the potential to shear through the side or basal lining system.
		Integrity	Not applicable

Given the foregoing, it is considered that the waste mass requires further assessment.

Leachate Collection System

In order to manage leachate generated by the waste mass a basal leachate drainage layer will be installed with associated infrastructure as part of the lining system.

Gas Collection System

Due to the nature of the waste to be deposited at Parry's Quarry Landfill gas will be generated. Therefore, a gas extraction and management system will be installed. This is described in detail within the Landfill Gas Risk Assessment.

2.1.6 Capping System Screening

The controlling factors that influence the stresses in the capping system are given in Table 2-6, below.

Table 2-6
Stability Components of Capping System

Mineral Cap	Stability	Pre-settlement slope inclination	Not applicable
	Integrity	Compressible waste	Not applicable
		Slope deformation	Not applicable
		Construction	Not applicable
		Cavities in waste	Not applicable
Geosynthetic/ mineral	Stability	Pre-settlement slope inclination	The proposed restoration profile will result in slopes of less than 1V:5H. Stability of the capping system at this gradient will need to be considered.
	Integrity	Compressible waste	The nature of the waste deposited will influence the magnitude of settlement. Domestic waste can experience settlement of up to 25%. However, inert waste is considered to have limited compressibility and no external factors will be present to cause anything other than deformations normally associated with inert waste settlement. Where the volume of settlement varies across a separation bund the influence of settlement on the capping system will need to be assessed.
		Slope deformation	No external factors will be present to cause anything other than deformations normally associated with waste settlement. This aspect is therefore not considered to require further assessment.
		Construction	The impact of construction plant on the proposed capping system will be assessed as part of stability.
		Cavities in waste	It is proposed that the final waste surface be graded and inspected prior to placement of the capping materials. This practice will eliminate the potential for near-surface cavities to be present. As such, this issue does not require further assessment.

Given the foregoing, it is considered that the integrity of the capping system requires further assessment.

2.2 Lifecycle Phases

This aspect of the assessment identifies the critical phases during the development of the landfill.

The landfill will be filled in phases dictated by the nature of waste, proximity to adjacent developments and installation of the lining system. Waste filling is likely to result in development of temporary waste slopes within each phase. Temporary waste gradients will be limited by basal cell extent and daily waste input. Placement will result in the worst case with a waste slope formed from formation level up to the proposed restoration level.

To ensure the SRA fully addresses the key issues throughout the life of the landfill, the side slope lining system, temporary waste slope (short term) stability and capping system stability are considered.

2.3 Data Summary

The following data are required as input for the analyses undertaken for this Stability Risk Assessment

- Material unit weight.
- Drained and undrained shear strength of soils and waste
- Elastic and compressibility properties of soils and waste.
- Elastic properties of interfaces.
- Properties of structural elements, if used, to represent geosynthetics within the basal and lining system in finite difference analysis.

It should be noted that there is no laboratory test data relating to the shear strength of the materials available on the site or those proposed for import to site.

There is limited available information on appropriate undrained or effective stress shear strength parameters for the in-situ material. Where no direct measurement of a particular property is available, reference has been made to regional borehole logs and relevant experience from within SLR in the same or similar materials.

The geotechnical parameter values adopted are discussed in more detail in Section 2.6.

2.4 Selection of Appropriate Factors of Safety

The factor of safety is the numerical expression of the degree of confidence that exists, for a given set of conditions, against a particular failure mechanism occurring. It is commonly expressed as the ratio of the load or action which would cause failure against the actual load or actions likely to be applied during service. This is readily determined by limit equilibrium slope stability analyses.

However, greater consideration must be given to analyses which do not report factors of safety directly. For example, a stress deformation analysis of shear strains within a steep side slope lining system would not usually indicate overall 'failure' of the model even though the strains could be high enough to indicate a failure of the *integrity* of the lining system. In such cases, it is necessary to define an upper limit for shear strains and to express the factor of safety as the ratio of allowable strain to actual strain.

Prior to determining appropriate factors of safety for the various components of the model, it is necessary to identify key 'receptors' and evaluate the consequences in the event of a failure (relating to both stability and integrity). Consideration of the following receptors is required:

- Groundwater
- Property - relating to site infrastructure, third party property
- Human beings (i.e. direct risk)

The Factor of Safety adopted for each component of the model would be related to the consequences of a failure.

2.4.1 Factor of Safety for Basal Subgrade

Whilst further assessment of this component is presented in Section 2.8.1, no formal analysis is undertaken; therefore, the selection of an appropriate factor of safety is not required.

2.4.2 Factor of Safety for Side Slope Subgrade

A factor of safety of 1.3 is considered appropriate when using conservative peak shear strength parameters.

2.4.3 Factor of Safety for Basal Lining System

An assessment is not required on this component as it has been screened out in Section 2.1.3.

2.4.4 Factor of Safety for Side Slope Lining System

A factor of safety of 1.3 is considered appropriate when using conservative peak shear strength parameters.

Where reduced shear strength parameters are adopted (for example, for very long term conditions, involving the 'fully-softened' or residual shear strength of the side slope lining system or interface parameters), it is considered that the factor of safety could be reduced to a value greater than unity, in accordance with the advice given in the Guidance.

2.4.5 Factor of Safety for Waste Mass

There are no domestic waste shear strength parameters available in the Guidance, therefore effective stress shear strength parameters have been used, based on the likely materials accepted at the site and SLR experience. In this case it is considered appropriate to adopt a factor of safety of 1.3.

2.4.6 Factor of Safety for Capping System

The factor of safety for the integrity of the synthetic capping system has been calculated using limiting yield strength of the geosynthetic LLDPE layer (11kN) over the axial force. A factor of safety of 1.3 is considered appropriate when using conservative peak shear strength parameters

2.5 Justification for Modelling Approach and Software

In order to perform a comprehensive Stability Risk Assessment, the components of the landfill development, as previously described in Section 1.2 of this document, have to be considered not only individually but also in conjunction with one another where relevant. Any analytical techniques adopted for such an assessment should adequately represent all of the considered scenarios, i.e. the different modelled phases of the lifecycle, for both confined and unconfined conditions (where appropriate). The methodology and the software should also achieve the desired output parameters for the assessment, e.g. determination of limit equilibrium factor of safety or calculation of strains within liner components.

The analytical methods used in this Stability Risk Assessment include:

- Limit equilibrium stability analyses for the derivation of factors of safety for the side slope subgrade and temporary waste slopes.
- Stress deformation analysis to determine strain on capping and lining systems.

The limit equilibrium analyses have been undertaken using the package Slope/W 2018, version 9.1 (Geo-Slope International). The Bishop[6] slip-circle and Morgenstern-Price[7] non-circular methods of analysis have been used.

The proprietary software Sigma/W 2018 Version 9.1 (Geo-Slope International) has been used for the capping system strain assessment. This is a two-dimensional explicit finite element programme, which simulates the behaviour of structures built of soil, rock or other materials that may undergo plastic flow when their yield limits are reached. Materials are represented by elements, or zones, which form a grid that is adjusted by the user to conform to the shape/cross section of the object (in this case, slopes) being modelled.

2.6 Justification of Geotechnical Parameters Selected for Analysis

The following sections present a justification for the various parameters used in the stability analyses based on the following criteria:

- An assessment of the suitability of non-site-specific data, where used.
- Methods for the derivation of the parameters adopted.

A summary of the geotechnical parameters used in the design and analysis of the development are presented in tabular form for each component of the landfill in s Selected for Capping Analyses

Capping analysis considers the interface between capping system elements. For the integrity analysis, the waste properties within the additional parameters used in the Sigma/W integrity assessment are discussed below.

A structural beam is required to model the interface between the restoration soils, geotextile and underlying waste. Material parameters required are the interface cohesion (c'), the total stress friction angle (phi), the shear modulus, unit weight and Poisson's ratio.

The shear strength of the interfaces present within the capping system has been adopted from the values reported in the Guidance.

The geotechnical parameters selected for the required analysis are presented below in Table 2-7 and the interface parameters in Table 2-8.

---

[6] Bishop, A.W., (1965), 'The use of the slip-circle in the stability analysis of slopes' Geotechnique
[7] Morgenstern, N.R and Price, V.E. (1965), 'The analysis of stability of general slip surfaces' Geotechnique.

Table 2-7.

The parameters used in the analysis have been:

- Adapted from similar work undertaken by SLR.
- Inferred from site specific data or other relevant published data.

It should be noted that the geotechnical parameters for limit equilibrium analysis include the shear strength and unit weight of each material within the model, plus pore water or gas pressure assumptions. Shear strength has been defined using total or undrained (s_u), and effective shear strength parameters of cohesion, (c'), and the angle of shearing resistance, (ø').

For integrity analysis additional properties required in the modelling include the elastic properties of the materials (Young's modulus, E and poisons ratio, ν).

2.6.1 Parameters Selected for Basal Subgrade Analysis

Analysis of the basal subgrade is not necessary as it has been screened out in Section 2.1.1.

2.6.2 Parameters Selected for Side Slopes Subgrade Analysis

The parameters required for the analysis of the side slope subgrade stability are the angle of shearing resistance, cohesion and unit weight of the materials forming the side slope subgrade.

2.6.3 Parameters Selected for Basal Lining System Analysis

Analysis of the basal lining system is not necessary as it has been screened out in Section 2.1.3. It will be considered as part of the waste mass analysis.

2.6.4 Parameters Selected for Side Slope Lining System Analyses

It should be noted here that the unconfined and confined side slope lining system analyses are distinct and dealt with in separate sections of this report. The former is considered in Section as part of the side slope subgrade assessment in Section 2.7.2 that considers the mineral element of the lining system placed as part of the buttress required to form the required side slope subgrade profile. The latter is undertaken as part of the Waste Mass Analysis (Section 2.7.5) since the side slope lining system integrity depends fundamentally upon the behaviour of the waste.

The parameters required for the side slope lining system analysis (undertaken as part of the Waste Mass Analysis) is the angle of shearing resistance and cohesion of the lining system's weakest interface. This has been assigned drained parameters and includes both peak and post peak values for the stability analysis. The parameters selected are presented in s Selected for Capping Analyses

Capping analysis considers the interface between capping system elements. For the integrity analysis, the waste properties within the additional parameters used in the Sigma/W integrity assessment are discussed below.

A structural beam is required to model the interface between the restoration soils, geotextile and underlying waste. Material parameters required are the interface cohesion (c'), the total stress friction angle (phi), the shear modulus, unit weight and Poisson's ratio.

The shear strength of the interfaces present within the capping system has been adopted from the values reported in the Guidance.

The geotechnical parameters selected for the required analysis are presented below in Table 2-7 and the interface parameters in Table 2-8.

Table 2-7 below.

2.6.5 Parameters Selected for Waste Analyses

In terms of non-hazardous waste strength, SLR adopts conservative values of effective shear strength parameters as derived from a study of geotechnical properties of municipal waste by Van Impe and Bouazza[8], these values being backed up in later work by Kavazanjian et al[9] and later confirmed in a research summary by Jotisankasa[10].

The unit weight of the waste is taken as 11kN/m^3, a value slightly higher than that generally adopted (10kN/m^3). This is based upon experience gained from SLR's previous modelling and stability work.

The waste material was assigned a Young's modulus of 500kPa with a Poisson's ratio of 0.29 throughout. The modulus values adopted for the non-hazardous waste are based on commonly accepted values and adjusted to give typical magnitudes of waste settlement; in this case 25% has been adopted

In terms of the waste strength, SLR has adopted conservative values of effective shear strength parameters; the values for c' and ø' adopted throughout the modelling were 5kPa and 25^o respectively.

For inert waste strength, SLR has adopted conservative values of effective shear strength parameters. These have been adopted based on assumptions made from SLR's recent experience.

The nature of the waste has been considered with the values presented in s Selected for Capping Analyses

Capping analysis considers the interface between capping system elements. For the integrity analysis, the waste properties within the additional parameters used in the Sigma/W integrity assessment are discussed below.

A structural beam is required to model the interface between the restoration soils, geotextile and underlying waste. Material parameters required are the interface cohesion (c'), the total stress friction angle (phi), the shear modulus, unit weight and Poisson's ratio.

The shear strength of the interfaces present within the capping system has been adopted from the values reported in the Guidance.

The geotechnical parameters selected for the required analysis are presented below in Table 2-7 and the interface parameters in Table 2-8.

[8] Van Impe, W. F. and Bouazza, A., "Geotechnical properties of MSW", draft version of keynote lecture, Osaka, 1996.
[9] Kavanjia, E. Jr., Matasovic, N., Bonaparte, R and Schmertman, G.R. (1995),'Evaluation of MSW properties for seismic analysis', Proc. Geoenvironment 2000, ASCE Special Geotechnical Publication, pp1126-1141.
[10] Jotisankasa, A., "Evaluating the Parameters that Control the Stability of Municipal Solid Waste Landfills", Master of Science Dissertation, University of London, September 2001.

Table 2-7.

2.6.6 Parameters Selected for Capping Analyses

Capping analysis considers the interface between capping system elements. For the integrity analysis, the waste properties within the additional parameters used in the Sigma/W integrity assessment are discussed below.

A structural beam is required to model the interface between the restoration soils, geotextile and underlying waste. Material parameters required are the interface cohesion (c'), the total stress friction angle (phi), the shear modulus, unit weight and Poisson's ratio.

The shear strength of the interfaces present within the capping system has been adopted from the values reported in the Guidance.

The geotechnical parameters selected for the required analysis are presented below in Table 2-7 and the interface parameters in Table 2-8.

Table 2-7
Geotechnical Design Parameters

Material	Unit Weight, γ (kN/m^3)	Effective cohesion, c′ (kPa)	Angle of Shearing Resistance, ø' (°)	Young's Modulus E (kPa)	Poisson's Ratio v	Typical Description
Domestic Waste	11	5	25	550	0.29	Non-hazardous biodegradable waste
Inert Waste	17	0.5	27	10000	0.29	Inert waste comprising predominantly soils
Engineered Clay	19	1 (0)	24.5 (18)	-	-	Low permeability clay liner and engineered clay to reduce slope gradients and increase basal elevation
Lining System Interface	19	0 (0)	22 (14)	-	-	Critical interface in lining system
LLDPE	-	0.5	1	120000	0.29	Artificial sealing geotextile. Values from typical material

*Shear strengths in parenthesis indicate post peak parameters

Table 2-8
Material Interface Parameters

	Peak		Post Peak	
Interface	**Apparent cohesion, c′ (kPa)**	**Angle of Shearing Resistance, ø' (°)**	**Apparent cohesion, c′ (kPa)**	**Angle of Shearing Resistance, ø' (°)**
Regulation Layer / LLDPE	0	24	0	18
LLDPE / Restoration Soils	0	24	0	18

2.7 Analyses

Details of the various Stability Risk Assessment analyses undertaken for the site are presented in the following sections.

2.7.1 Basal Subgrade Analysis

Analysis of the basal subgrade is not necessary, as it has been screened out in Section 2.1.1.

2.7.2 Side Slope Subgrade Analysis

The stability analysis program Slope/W has been used to analyse the section using the Morgenstern-Price[7] form of analysis.

A single cross section is considered as being representative of the typical worst case for the proposed slope geometry. The analysis assesses the short to medium term stability of the material. It considers a slope 20m high at a gradient of 1V:2.7H.

In order to construct the slope, it is recommended that the clay is placed in lifts 5m high. Lifts are limited to 5m high for health and safety reasons and to ensure adequate access to the area is available. The results are presented in **Error! Reference source not found.**.

Table 2-9
Summary of Stability Analysis for Side Slope Subgrade

Figure	File	Method	Factor of Safety	Shear Strength		Comments
				ϕ′ (°)	c′ (kPa)	
SRA1-1	SRA1	Drained Circular	1.322	24.5	1	1V:2.7H gradient.

2.7.3 Basal Lining System Analysis

Analysis of the basal lining system is not necessary as it has been screened out in Section 2.1.3.

2.7.4 Side Slope Lining System Analysis

Unconfined Lining System Stability

The unconfined side slope lining system will comprise low permeability site won clay placed to achieve formation level and form the mineral lining system at the base of the lining system to a minimum of 0.5m thickness. It has been assumed the geotechnical characteristics of this horizon will be identical to the clay buttress placed to form the side slope subgrade profile. Analysis of this element has been carried out as part of the side slope subgrade analysis in Section 2.7.5.

Confined Liner Stability

Analysis of the confined side slope lining system stability has been undertaken as part of the waste mass analysis, as described in Section 2.7.5. This is because both stability of the lining system and the waste mass are inter-related.

2.7.5 Waste Analysis

In considering the stability of the waste mass, the stability and integrity of the geological lining system would normally be considered as they are intrinsically linked. The three potential modes of failure considered are:

- Mode 1 - Critical Slip Surfaces passing solely through the waste
- Mode 2 - Critical Slip Surfaces passing through the waste and the basal lining system.
- Mode 3 - Critical Slip Surfaces passing down through the side slope lining system and along the basal lining system.

Mode 2 and Mode 3 analyses consider a basal interface representing the weakest interface between the liner elements.

Analyses have been dealt with in terms of circular and non-circular 2-D limit equilibrium using the computer program Slope/W. Stability analysis outputs are presented in Appendix SRA2.

The waste material will be tipped in phases based on waste input and site phasing. The temporary waste slope gradients are considered as being the critical condition.

Mode 1 Waste Mass Stability

Mode 1 analysis has been carried out on the anticipated maximum 20m high waste slope. Separate analyses have been carried out to consider both domestic and inert waste. Waste types will be separated by bunds constructed of engineered clay placed in lifts in line with the waste mass.

The results of the Mode 1 analyses are summarised

Table 2-10 below and presented in Appendix SRA2. Mode 1B considers partial saturation of the waste mass through the application of pore water ratio (r_u) within the waste mass.

Analyses of the domestic waste slopes are presented in Figures SRA2-1 and SRA2-2. Analyses indicate a 20m high domestic waste slope constructed at a gradient of 1V:2.5H returns an acceptable factor of safety in Mode 1A and Mode 1B. A piezometric line has been applied at 2m above the base of the domestic waste mass to represent the maximum leachate elevation. The leachate level will be maintained below the face of the slope by the basal leachate drainage system.

Figure SRA2-4 shows for inert waste in order to obtain an acceptable factor of safety slopes should be constructed at a maximum gradient of 1V:3H.

Table 2-10
Summary of Waste Stability Analysis for Mode 1

Figure	File	Method	Waste Type	Factor of Safety	r_u	Comments
SRA2-1	SRA2	Drained Circular	Domestic Waste	1.435	0	Mode 1A: 20m high slope at 1V:2.5H gradient. Failure solely within waste mass. Acceptable (FOS >1.3)
SRA2-2	SRA2	Drained Circular		1.315	0.1	Mode 1B: 20m high slope at 1V:2.5H gradient. Failure solely within waste mass. Acceptable (FOS >1.3)
SRA2-3	SRA2	Drained Circular	Inert Waste	1.572	0	Mode 1A: 20m high slope at 1V:3H gradient. Failure solely within waste mass. Acceptable (FOS >1.3)
SRA2-4	SRA2	Drained Circular		1.435	0.1	Mode 1B: 20m high slope at 1V:3H gradient. Failure solely within waste mass. Acceptable (FOS >1.3)

Figures SRA2-1 to SRA2-4 demonstrates a factor of safety in excess of 1.3, which is considered to be acceptable.

Mode 2 Waste Mass Stability

Mode 2 considers a potential failure mechanism that passes through the waste and into the basal lining system. A 20m high waste mass has been analysed for with a waste slope gradient of 1V:2.5H in domestic waste and 1V:3H in inert waste.

A piezometric line has been applied at 2m above the base of the domestic waste mass to represent the maximum leachate elevation. The leachate level will be maintained below the face of the slope by the basal leachate drainage system.

Output drawings from Slope/W, detailing the slope profiles and the critical slip planes analysed for Mode 2, are presented in Appendix SRA2. The factors of safety reported for peak and softened interface analyses are summarised in

Figure	File	Method	Waste Type	Factor of Safety	r_u	Comments
SRA2-5	SRA2	Drained Circular	Domestic Waste	1.434	0	Mode 2A: Peak shear strength in basal interface. Acceptable (FOS >1.3)
SRA2-6	SRA2	Drained Circular		1.316	0.1	Mode 2B: Peak shear strength in basal interface. Acceptable (FOS >1.3)
SRA2-7	SRA2	Drained Circular		1.206	0	Mode 2C: Residual shear strength in basal interface. Acceptable (FOS > 1.0)
SRA2-8	SRA2	Drained Circular		1.127	0.1	Mode 2D: Residual shear strength in basal interface. Acceptable (FOS > 1.0)
SRA2-9	SRA2	Drained Circular	Inert Waste	1.566	0	Mode 2A: Peak shear strength in basal interface. Acceptable (FOS >1.3)
SRA2-10	SRA2	Drained		1.430	0.1	Mode 2B: Peak shear strength in basal

Figure	File	Method	Waste Type	Factor of Safety	r_u	Comments
		Circular				interface. Acceptable (FOS >1.3)
SRA2-11	SRA2	Drained Circular		1.311	0	Mode 2C: Residual shear strength in basal interface. Acceptable (FOS > 1.0)
SRA2-12	SRA2	Drained Circular		1.199	0.1	Mode 2D: Residual shear strength in basal interface. Acceptable (FOS > 1.0)

below.

Modes 2B and 2D consider partial saturation of the waste mass through the application of pore water ratio (r_u) within the waste mass.

Under peak shear strength conditions for the basal lining system acceptable factors of safety are achieved under both favourable and unfavourable pore pressure conditions, as shown in Figures SRA2-5, SRA2-6, SRA2-9 and SRA2-10.

Table 2-11
Summary of Waste Stability Analysis for Mode 2

Figure	File	Method	Waste Type	Factor of Safety	r_u	Comments
SRA2-5	SRA2	Drained Circular	Domestic Waste	1.434	0	Mode 2A: Peak shear strength in basal interface. Acceptable (FOS >1.3)
SRA2-6	SRA2	Drained Circular		1.316	0.1	Mode 2B: Peak shear strength in basal interface. Acceptable (FOS >1.3)
SRA2-7	SRA2	Drained Circular		1.206	0	Mode 2C: Residual shear strength in basal interface. Acceptable (FOS > 1.0)
SRA2-8	SRA2	Drained Circular		1.127	0.1	Mode 2D: Residual shear strength in basal interface. Acceptable (FOS > 1.0)
SRA2-9	SRA2	Drained Circular	Inert Waste	1.566	0	Mode 2A: Peak shear strength in basal interface. Acceptable (FOS >1.3)
SRA2-10	SRA2	Drained Circular		1.430	0.1	Mode 2B: Peak shear strength in basal interface. Acceptable (FOS >1.3)
SRA2-11	SRA2	Drained Circular		1.311	0	Mode 2C: Residual shear strength in basal interface. Acceptable (FOS > 1.0)
SRA2-12	SRA2	Drained Circular		1.199	0.1	Mode 2D: Residual shear strength in basal interface. Acceptable (FOS > 1.0)

Figure SRA2-7, SRA-8, SRA2-11 and SRA2-12 assume the angle of shearing resistance in the basal interface at the base of the landfill is in a long term softened condition, with a value of $\phi'=14^{o}$ and c'=0kPa. Since softened shear strength values have been assumed, the allowable factor of safety has been reduced to greater than 1.0, in line with the recommendations made in the Guidance.

The stability analysis demonstrates that the factor of safety for this scenario drop as the pore water pressure ratio (r_u) value rises; all of the results are considered to be acceptable.

Mode 3 Waste Mass Stability

Mode 3 considered a potential, non-circular slip surface passing down through the side slope lining system and along the basal lining system.

The analysis considers to scenarios:

- Peak shear strength conditions in the basal lining system with softened shear strength conditions in the side slope lining system; and,
- Softened shear strength conditions in both the basal and side slope lining systems.

The results are presented in Table 2-12 below and the analysis sections are presented in Appendix SRA2.

Table 2-12
Summary of Waste Stability Analysis for Mode 3

Figure	File	Method	Waste Type	FoS	Side Slope Lining Interface ø′ (°)	Basal Lining Interface ø′ (°)	c′ (kPa)	Comments
SRA2-13	SRA2	Drained Non-circular	Domestic Waste	2.569	14	22	0	Peak shear strength for basal lining system. Acceptable (FOS >1.3)
SRA2-14	SRA2	Drained Non-circular		1.833	14	14	0	Softened shear strength for basal lining system. Acceptable (FOS >1.0)
SRA2-15	SRA2	Drained Non-circular	Inert Waste	2.770	14	22	0	Peak shear strength for basal lining system. Acceptable (FOS >1.3)
SRA2-16	SRA2	Drained Non-circular		1.950	14	14	0	Softened shear strength for basal lining system. Acceptable (FOS >1.0)

Both scenarios return an acceptable factor of safety for both waste types as shown in Figures SRA2-13 to SRA2-16.

2.7.6 Capping Analysis

Capping Integrity

Capping analysis considers the integrity of the artificial sealing liner (LLDPE) overlying the regulation layer.

Numerical modelling has been undertaken to determine the potential effects of differential settlement of the proposed waste mass across a separation bund. The Sigma/W model configuration is based upon information interpreted from the proposed maximum waste thickness.

The key features of the Sigma/W model are described below.

- The worst case interface between the waste masses and lining system has been derived. The key issue under consideration in the analysis is the generation of tensions, specifically along the LLDPE across the separation bund. Examination of the available information indicates that maximum waste height will be approximately 25m.

- The capping system is represented by a 1m thick restoration layer and 0.3m of regulation soils. Within this is a structural beam representing the 1mm HDPE in both waste phases. Slip surface interfaces have been applied to the beam to model both the LLDPE to regulation layer and LLDPE to restoration soils.

- In order to induce the required degree of settlement in the domestic waste mass the material is modelled as having very low elastic stiffness parameters. The inert waste is modelled to have high elastic stiffness parameters. Settlement of the waste is induced by applying load to the upper surface of the model. However, it is pointed out that the absolute elastic parameters of the waste material are not critical in this case. The key goal is to induce the required degree of settlement within the waste in order to reflect the desired settlement (25%).

- The base of the model represents a relatively stiff boundary and the sides of the model are fixed in the 'x' direction to prevent lateral movement distorting the results.

Sigma/W Model Output

As previously discussed, the key aspect for the capping system performance is the tension induced in the LLDPE across a bund between two waste cells of different material.

Drawing SRA3-1 of Appendix SRA3 presents the result of constant vertical loading (50kPa) to generate 25% settlement of the waste immediately adjacent to the bund. The highest loading has been applied to the waste mass nearest the bund to ensure the worst-case scenario, with the highest tension is applied to the LLDPE.

Drawing SRA3-2 of Appendix SRA3 presents graphically the axial force the LLDPE membrane is subjected to across the engineered separation bund. The graph shows that with the modelled parameters the maximum axial force the membrane is exposed to is -0.62kN (a negative value as the membrane is under tension). The highest stress occurs at 10m from the left-hand edge of the model, at the crest of the bund.

Comparison with Performance Criteria

The results of the modelled waste scenario show tension in the LLDPE membrane well below the given yield strength of the intact material. Typical yield strength of a 1mm LLDPE is in the region of 11kN, suggesting a factor of safety against failure of the LLDPE of approximately 18. This factor of safety assumes that any failure will have occurred within the LLDPE material itself.

Capping Stability

Additional analyses have been carried out to determine the stability of the critical interfaces within the capping system when placed at pre-settlement gradients of up to 1V:4H. It has been assumed, for the purposes of the stability risk assessment, that if the steepest parts of the slopes are stable then all shallower slopes and post settlement slopes must also be stable.

No drainage layer is proposed between the restoration soils and the LLDPE hence a Parallel Submerged Ration (PSR) or 0.4 (or higher) has been used, as defined by Jones and Dixon[11]. This PSR value equates to 40% saturation of the capping soils and is considered to be a conservative value based on the slope gradient.

Analyses applying the laboratory interface shear strength values presented in Table 2-8 have been undertaken following the principals set out in the Guidance. The results are presented as Appendix SRA3-3 and in Table 2-13, below. Figure SRA3-4 (Appendix SRA3) illustrates the forces and parameters used in the analysis.

---

[11] Jones, D.R.V. & Dixon, N. (2002) Stability of landfill lining systems: Report No. 2 Guidance, R&D Technical Report P1-385/TR2, Environment Agency

Table 2-13 Summary of Capping Interface Stability Analysis

Case No.	Slope Gradient	Slope Height (m)	Critical Interface		Parallel Sub-merged Ratio	Worst case interface		
			Friction Angle (°)	Cohesion (kPa)		F of S	Tension	Interface
1	1V:5H	17	24 (18)	0 (0)	0.4	1.79 (1.34)	No	Regulation Layer /LLDPE
2	1V:4H	17	24 (18)	0 (0)	0.4	1.44 (1.08)	No	Regulation Layer / LLDPE

When adopting the peak shear strength for the soil interfaces with the GCL and a parallel submerged ratio of 0.4, the minimum reported factor of safety is 1.44. For assumed residual shear strength conditions the minimum factor of safety reported is 1.08. All of the analysed conditions are above the minimum criteria for stability.

Closed Form Construction Plant Analysis

An additional analysis has been carried out that considers the integrity of the LLDPE within the capping system under plant loading.

The integrity of 1V:5H and 1V:4H capping slopes with a D6 dozer tracking up slope has been assessed using the procedure proposed by Kerkes[12]. The results of the analyses are presented as Appendix SRA3-5 and SRA3-6.

At a slope gradient of 1V:5H the analyses have been undertaken assuming 0kN tension is accommodated in the LLDPE and with the dozer placing 0.6m of soils in the first lift. The calculated factor of safety is 1.43 which is above limit of acceptability (min FoS 1.3).

At a gradient of 1V:4H it is assumed that 5kN/m of tension is accommodated in the LLDPE. Typical yield strength of a 1mm LLDPE is in the region of 11kN, therefore tension is within acceptable limits. Under these conditions the calculated factor of safety is 1.38 and is considered acceptable. The risk of impact on the LLDPE is considered to be low and the factor of safety is acceptable.

[12] Kerkes, D.J., (1999), 'Analysis of equipment loads on geosynthetic liner systems', Proc. Geosynthetics 1999.

2.8 Assessment

2.8.1 Basal Subgrade Assessment

Assessment of this component is not required as it was eliminated from consideration by the screening process (Section 2.1.1).

2.8.2 Side Slope Subgrade Assessment

The analysis of the side slope subgrade indicated that the placed clay forming the lining system element of the side slope lining system required further investigation. The assessment considers the stability of designed 1V:2.7H gradient slopes. The slope is considered to have an acceptable factor of safety. Lifts should be placed to a maximum of 5m high.

2.8.3 Basal Lining System Assessment

Assessment of this component is not required as it was eliminated from consideration by the screening process (Section 2.1.3). Those components that have been assessed are considered under Section 2.8.5.

2.8.4 Side Slope Lining System Assessment

The analysis of the side slope lining system indicated that the placed clay forming the lining system element of the side slope lining system required further investigation. The assessment considers the stability of designed 1V:2.7H gradient slopes. The slope is considered to have an acceptable factor of safety. Lifts should be placed to a maximum of 5m high.

Assessment of the confined side slope lining system stability is addressed in Section 2.8.5 below.

2.8.5 Waste Assessment

Waste Mass Stability

This SRA incorporates analyses of lining system stability since this component plays a role in waste mass stability. The assessment considers temporary waste slopes within the domestic and inert wastes.

The site will be in filled in a number of phases. This has the potential to generate temporary waste slopes which have been modelled at a gradient of between 1V:2.5H and 1V:3H up to a maximum of 20m high, excluding capping.

Stability analysis considers three potential modes of failure:

- Mode 1 - Critical Slip Surfaces passing solely through the waste
- Mode 2 - Critical Slip Surfaces passing through the waste and the basal lining system.
- Mode 3 - Critical Slip Surfaces passing down through the side slope lining system and along the basal lining system.

Each assessment considers a worst case scenario with elevated pore pressure within the waste mass. Additionally, Mode 2 and Mode 3 analyses consider both peak and residual (softened) strength parameters within the lining system.

The stability assessment demonstrated that when temporary waste slopes are constructed to the maximum waste height of 20m high domestic waste slopes maintain an adequate factor or safety at 1V:2.5H and inert waste slopes at a maximum gradient of 1V:3H. Slope height will be limited by waste input and should be placed in lifts to ensure adequate machine access and maintain a buttress against cell bunds.

2.8.6 Capping Assessment

The assessment of the capping system determined there will be no integrity issues associated with the intact LLDPE under the anticipated waste settlements adjacent to an engineered bund. However, the failure of joins or welds within the material is not discounted.

The capping interface assessment indicated that at gradients of up to 1V:4H all of the analysis conditions are above the minimum criteria for stability.

3.0 MONITORING

3.1 The Risk Based Monitoring Scheme

Based upon the foregoing Stability Risk Assessment, a simple risk-based monitoring scheme is considered appropriate for the future development of the landfill. The monitoring is limited to ensuring compliance with the tipping rules and monitoring of groundwater levels.

3.2 Basal Subgrade Monitoring

No additional instrumentation is deemed as being required during construction or post closure.

3.3 Side Slope Subgrade Monitoring

No additional instrumentation is deemed as being required during construction or post closure.

3.4 Basal Lining System Monitoring

Monitoring during construction will comprise construction quality assurance to ensure compliance with the construction specification.

No additional instrumentation is deemed as being required during construction or post closure.

3.5 Side Slope Lining System Monitoring

Monitoring during construction will comprise construction quality assurance to ensure compliance with the construction specification.

No additional instrumentation is deemed as being required during construction or post closure.

3.6 Waste Mass Monitoring

Tip faces and surrounding areas should be inspected daily for signs of failure.

No other specific monitoring is required for the waste other than to record waste elevations across the site.

3.7 Capping Monitoring

Monitoring during construction will comprise construction quality assurance to ensure compliance with the construction specification.

No additional instrumentation is deemed as being required during construction or post closure.

APPENDIX SRA1

Side Slope Lining system Analysis

APPENDIX SRA2

Waste Mass Analysis

APPENDIX SRA3

Capping System Analysis

EUROPEAN OFFICES

United Kingdom

AYLESBURY
T: +44 (0)1844 337380

BELFAST
T: +44 (0)28 9073 2493

BRADFORD-ON-AVON
T: +44 (0)1225 309400

BRISTOL
T: +44 (0)117 906 4280

CAMBRIDGE
T: + 44 (0)1223 813805

CARDIFF
T: +44 (0)29 2049 1010

CHELMSFORD
T: +44 (0)1245 392170

EDINBURGH
T: +44 (0)131 335 6830

EXETER
T: + 44 (0)1392 490152

GLASGOW
T: +44 (0)141 353 5037

GUILDFORD
T: +44 (0)1483 889800

LEEDS
T: +44 (0)113 258 0650

LONDON
T: +44 (0)203 805 6418

MAIDSTONE
T: +44 (0)1622 609242

MANCHESTER
T: +44 (0)161 872 7564

NEWCASTLE UPON TYNE
T: +44 (0)191 261 1966

NOTTINGHAM
T: +44 (0)115 964 7280

SHEFFIELD
T: +44 (0)114 245 5153

SHREWSBURY
T: +44 (0)1743 23 9250

STAFFORD
T: +44 (0)1785 241755

STIRLING
T: +44 (0)1786 239900

WORCESTER
T: +44 (0)1905 751310

Ireland

DUBLIN
T: + 353 (0)1 296 4667

France

GRENOBLE
T: +33 (0)4 76 70 93 41