GEOTECHNICAL

ENVIRONMENTAL

WYG ENVIRONMENTAL LTD.

CRIMPLESHAM INERT LANDFILL SITE

Stability Risk Assessment Report

GEC JOB NO: GE190520110

Geotechnical and Environmental Ltd

10 Seven Acres Road, Weymouth, Dorset. DT36DG

Tel: +44 (0)800 0407051 **www.geosure.co.uk**

WYG ENVIRONMENTAL LTD.

CRIMPLESHAM INERT LANDFILL SITE

Stability Risk Assessment

GEC JOB NO: GE190520110

Document History:

Reference: **GE19052/DF/SRA**		
Date of Issue	Document Description	Prepared
01/10/2019	Stability Risk Assessment	Dr David Fall CGEOL FGS
September 2020	Stability Risk Assessment V2	Dr David Fall CGEOL FGS

GEOTECHNICAL AND ENVIRONMENTAL CONSULTING LTD., 10 Seven Acres Road, Weymouth, Dorset. DT3 6DG.
Telephone: +44 (0)800 0407051 www.geosure.co.uk

CONTENTS

LIST OF TABLES

LIST OF APPENDICES

1.0 INTRODUCTION

Report Context

1.1 The operator of the installation is Frimstone / Mick George Limited (MGL).

1.2 WYG Environmental Ltd. (WYG) have instructed Geotechnical & Environmental Consulting Ltd. (GEC) to undertake a Stability Risk Assessment (SRA) to form part of an Environmental Permit Application for Crimplesham Inert Landfill Site, Crimplesham, Norfolk.

1.3 It is understood that the void, to be backfilled with inert waste, will be formed by sand and gravel extraction works. Systematic filling with inert waste will commence on completion of mineral extraction work provided the necessary regulatory permissions are received.

1.4 The following documents and drawings have been supplied by the Client and referred to in the compilation of this Report:

- Crimplesham Inert Landfill Site, Environmental Permit Application: Environmental Setting and Site Design. Dated September 2020.
- Crimplesham Inert Landfill Site, Environmental Permit Application: Site Condition Report. Dated September 2020.
- Crimplesham Inert Landfill Site, Environmental Permit Application: Environmental Risk Assessment. Dated September 2020.
- Crimplesham Inert Landfill Site, Environmental Permit Application: Environmental Management and Monitoring Plan. Dated September 2020.
- Crimplesham Inert Landfill Site, Environmental Permit Application: Operating Techniques. Dated A September 2020.

1.5 This Report has been completed in conjunction with the Environmental Setting and Site Design Report (ESSD) (September 2020). It is not a standalone document and factual data related to the site, its setting and receiving environment are located in the ESSD and referred to in this document. All drawings referred to in this SRA are to be found in the ESSD unless otherwise stated. This document has been prepared in accordance with the Stability Risk Assessment Report Template (Version 1 – March 2010).

Conceptual Stability Site Model

Location

1.6 This Stability Risk Assessment refers to the area that is included within the Environmental Permit Application boundary shown on Drawing No. P2734 D3, Rev F – Working Plan and Environmental Permit Boundary.

1.7 The application site forms part of the Crimplesham Quarry site which is located approximately 855m east from the village of Crimplesham in Norfolk. The Crimplesham Quarry site comprises two areas of land that are separated by a road (Main Road). This application solely relates to the southern section of the quarry which is centred at approximate National Grid Reference (NGR) 566346 303464.

1.8 The site environs generally slope gently to the south such that the thickness of the superficial deposits thin in the same direction.

Regional Geology

1.9 With reference to British Geological Survey Sheet 159 Wisbech 1:50000 Sold & Drift, the site is located on Lowestoft Formation (LOFT)) overlying West Melbury Marly Chalk Formation (WMCH) of the Grey Chalk Subgroup. The BGS geological map indicates the presence of the Gault Formation to be present in the area, outcropping to the south of the Permit Application Area.

1.10 The BGS Lexicon of Named Rock Units describes the LOFT as an extensive sheet of chalky till, together with outwash sands and gravels, silts and clays. The till is characterised by its chalk and flint content. The carbonate content of the till matrix is about 30%; whilst tills of the underlying underlying Happisburgh Formation have less than 20%. The Lexicon describes the WMCH as; buff, grey and off-white, soft, marly chalk and hard grey limestone arranged in couplets; whilst the Gault Clay (GLT) comprises pale to dark grey or blue-grey clay or mudstone.

1.11 1no. borehole is available from the British Geoscience Database and is located to the north of Main Road, approximately 300m north of the centre of the Permit Application Area. This borehole indicates the geology to comprise:-

GL to 9.15m	Sand & Gravel (Boulder Clay)
9.15 to 10.05m	Chalk
10.05 to 18.30m	Gault Clay

1.12 The regional borehole indicates there to be only a very limited thickness of Chalk present in the area with Gault Formation being identified at 10.05mbgl.

1.13 No geological structures are mapped within 1km of the site. The regional dip of the geological stratum is shown to be very shallow towards the east.

Local Geology

1.14 7 boreholes were drilled around the periphery of the site to allow the installation of groundwater monitoring standpipes. A precis of the stratigraphy encountered in these boreholes is presented in Table SRA 1 and in brief shows the site to be underlain by sand and gravel of the Lowestoft Formation overlying the grey clay of the Gault Formation.

1.15 WMCF was reported in the south of the site in BHs D, E & F; however, the absence of any Limestone interbeds, a diagnostic feature of the WMCF, suggest these materials are part of the LOFT, which is described as a chalky till in the BGS Lexicon. This interpretation is in keeping with the stratigraphy reported in the regional borehole where WMCF is also absent.

Table SRA1 Local Stratigraphy at Crimplesham Inert Landfill Site

Borehole No.	Lowestoft Formation		West Melbury Marly Chalk		Gault Clay Formation	
	From (mbgl)	Thickness (m)	From (mbgl)	Thickness (m)	From (mbgl)	Thickness (m)
BHA	GL	12.80	N/E		12.80	>2.20
BHB	GL	>20.00	N/E			
BHC	GL	>20.00	N/E			
BHD	GL	8.30	N/E		8.30	>2.70
BHE	GL	7.40	N/E		7.40	>6.60
BHF	GL	10.50	N/E		10.50	>1.50
BHG	GL	12.1	N/E		12.1	>1.90

GL – Ground Level
N/E – Not Encountered

Lowestoft Formation (LOFT)

1.16 LOFT was encountered in all boreholes and increased in thickness in a northerly direction such that the thickest sequences (>20.00m) were identified in the north of the site. The LOFT comprised a brown sand and flint gravel. In the south the LOFT contained beds described as both white chalk and marly chalk.

Gault Clay Formation (GLT)

1.17 The GLT was encountered in all boreholes where it formed the basal unit of the ground investigation. The GLT was described as a grey clay.

Hydrogeology

1.18 On the Environment Agency's Aquifer Designation the Lowestoft Formation is recorded as a Secondary Undifferentiated Aquifer; whilst the underlying Gault Clay Formation is designated as a non-aquifer.

1.19 With reference to the Multi-Agency Geographic Information for the Countryside's (MAGIC) website, the site is not situated within a Groundwater Source Protection Zone (GSPZ).

1.20 The nearest surface water feature to the site is an unnamed pond which is located approximately 415m south from the application site.

1.21 According to the Flood Map for Planning Service (FMPS), the application site is not situated in an area at risk of flooding.

1.22 Groundwater monitoring has been carried out in BHs A to G within the permit application area. The levels recorded between 09/18 and 06/20 range from 19.31mOD (BH C) to 21.71mOD (BH G).

Basal Subgrade Model

1.23 The base level of the mineral extraction void is 24mOD which, based on the BHs A-G, which means the basal subgrade will comprise the Lowestoft Formation.

1.24 Groundwater monitoring of Boreholes A-G indicates standing groundwater levels to be below the proposed base of the void level.

Basal Lining System

1.25 Prior to the commencement of landfilling, a geological barrier will be engineered using imported clay. The geological barrier will be constructed in compliance with the Environmental Permitting Regulations: Inert Waste Guidance 2010 which specifies that a geological barrier shall have a hydraulic conductivity of less than 1m at 1×10^{-7}m/s or 0.5m at 5×10^{-8}m/s.

Side Slope Subgrade Model

1.26 The side slope subgrade model will comprise Lowestoft Formation consisting of sands and gravels in varying proportions. Given an extraction void basal elevation of 24mOD the highest side slope height will be approximately 11.00m in the north of the site area.

1.27 Based on cross-sections of the proposed workings supplied by the Client, the post extraction side slope subgrade will be left at a gradient of 1(H): 1(V) (45°).

1.28 Prior to the construction of the side slope liner the side slopes will be slackened to a minimum of 2.5(H) : 1(V) (22°) by the placement and compaction of imported materials.

1.29 Groundwater monitoring has indicated groundwater to be at between 19.5 and 21.6mOD. Based on the ground levels recorded at the locations of BHs A-G, groundwater will be a minimum of 2.40m below the base of the void.

Side Slope Lining Model

1.30 The quarry sides will be shaped using on site materials to achieve a stable long-term side slope subgrade.

1.31 The side slope liner will placed against the 2.5(H) : 1(V) reshaped side slope subgrade.

1.32 The side slope liner will be formed using selected imported fine-grained material. If a single source material is unavailable for the construction of the side slope liner a selection protocol will be used to ensure the appropriateness of the material.

1.33 The geological side slope barrier will be constructed in compliance with the Environmental Permitting Regulations: Inert Waste Guidance 2010 which specifies that a geological barrier shall have a hydraulic conductivity of less than 1m at 1×10^{-7}m/s or 0.5m at 5×10^{-8}m/s.

Inert Waste Model

1.34 It is proposed that the waste deposited at the Crimplesham regulated waste facility will be from known sources largely comprising derived arisings and other materials from large earthwork contracts.

1.35 The geology of the local area is variable and comprises both coarse- and fine-grained materials. With respect to stability the worst case would be an inert waste mass comprised entirely of fine-grained materials. Therefore, the inert waste model will comprise a generic fine-grained material and the characteristic geotechnical parameters attributed to this material will be based on a number of sources.

Table SRA2: Bibliography of Published Sources used in the Determination of the Characteristic Geotechnical Parameters of the Inert Waste

Author	Date	Title
Carter M., & Bentley S.P.	2016	Soil Properties and Correlations 2nd. Ed.
Look B.	2007	Handbook of Geotechnical Investigation and Design Tables
Duncan J.M., & Wright, S.G.	2005	Soil Strength & Slope Stability
CIRIA C583	2004	Engineering in the Lambeth Group[1]
Hight D.W., McMillan, F., Powell, J.J.M., Jardine, R.J., & Allenou, C.P.	2003	Some Characteristics of the London Clay: IN Tan et al. (Eds.) Characterisation and Engineering Properties of Natural Soils.[1]

[1] *the inclusion of these two strata specific references should not be taken as a suggestion of the Inert Waste content.*

Restoration Soils Model

1.36 In accordance with the requirements of the Landfill Directive, an engineered cap (clay or plastic) is not required.

1.37 On completion of filling to final levels, the site will be restored to agricultural land in accordance with the approved restoration plan.

1.38 Due to the nature of the waste gas monitoring and control systems are not required.

2.0 STABILITY RISK ASSESSMENT

Risk Screening

Basal Subgrade Screening

2.1 The basal subgrade will be formed of the in-situ Lowestoft Formation. As the void is to be formed by the excavation of material there will be a net unloading of the basal subgrade. The replacement of the excavated material with inert waste will not fully reload the soil as there is a difference in the unit weight of the excavated material and the replaced inert waste which should only cause the elastic recompression of the basal subgrade.

2.2 Therefore, a full stability analysis of the basal subgrade is not required.

Basal Lining System Screening

2.3 The basal liner will comprise 0.50m or 1.00m of imported clay material placed upon the in-situ Lowestoft Formation. Provided the imported liner material is subjected to appropriate conformance testing, no detailed stability assessment of this component is considered necessary.

Side Slope Subgrade Screening

2.4 The side slopes will be formed as part of the sand and gravel extraction process and will comprise Lowestoft Formation. The side slope subgrade of the mineral extraction void are shown, on cross-sections provided by the client, to be stable at a gradients of 1(H) : 1(V).

2.5 The gradient of the side- slope subgrade is to be slackened to a minimum of 1 (V) : 2.5 (H) by the placement of locally derived granular material (Reworked Lowestoft Formation).

2.6 A full stability analysis of the subgrade model is considered necessary.

Side Slope Lining System

2.7 An artificially established side lining system, comprising imported selected material with a minimum perpendicular thickness of 0.50 or 1.00m, will be placed on the side slopes to achieve a maximum face angle of 1(V) : 2.5(H).

2.8 Analysis of this component is considered necessary to investigate both the short- and long-term stability of this element as well as the effect of softening of the clay material if left exposed for long periods of time.

Waste Mass Screening

2.9 Inert waste placed at the site will largely comprise natural soils from local earthwork projects.

2.10 A full stability analysis of both the temporary and permanent waste faces will be carried out as part of this stability risk assessment.

Capping System Screening

2.11 There is no requirement for an engineered cap as this site. Restoration soils will be placed to achieve a landform similar to the pre-extraction levels. Due to the type of the waste to be placed at the site no gas or uplift pressures will be generated within the waste mass.

2.12 Based on the above no detailed analysis of the restoration landform is considered necessary.

Justification of Modelling Approach and Software

2.13 Two-dimensional limit equilibrium stability analyses were used in the assessment of the stability of the subgrade and subgrade liner. The method of analysis used in each particular case was determined from an examination of the form of failure being considered.

2.14 The stability analyses of the slopes were carried out using the Slope/W computer programme.

2.15 The Morgenstern and Price Method was used in the analyses to determine the factor of safety against instability for both total stress and effective stress conditions.

Justification of Geotechnical Parameters Selected for Analyses

Parameters Selected for Basal Subgrade Analyses

2.16 The basal subgrade will be included the analysis of both the side slope subgrade and waste mass. The characteristic properties of the basal subgrade will be the same as those presented for the side slope subgrade (SRA3).

Parameters Selected for Side Slopes Subgrade Analyses

2.17 Side Slope Subgrade analyses will be carried out on the side slopes formed in the Lowestoft Formation. The characteristic geotechnical parameters to be used in the analysis subgrade are presented in Table SRA3.

Table SRA3 Side Slope Subgrade Stability – Summary of Characteristic Geotechnical Data

Stratum	Parameter		Characteristic Value		Source
Lowestoft Formation	Unit Weight	γ_k	20kN/m^3		BS8002 Table 1
	Shear Strength	c_k, ϕ_k	0kN/m^2	35˚	Published values
Reworked Lowestoft Formation	Unit Weight	γ_k	18kN/m^3		Reduction due to slight decrease in relative density
	Shear Strength	*ck, fk*	0kN/m^2	32°	

Parameters Selected for Side Slopes Liner Analyses

2.18 The side slope liner is to be constructed using an appropriate imported fine-grained material. Typical values for remoulded clay materials (1,3) have been used to define the characteristic geotechnical values of the side slope liner material (Table SRA 4).

Table SRA4: Side Slope Liner Stability – Summary of Characteristic Geotechnical Data

Material	Unit Weight	Total Stress		Effective Stress	
	γ_k (kN/m^3)	c_{uk} (kN/m^2)	ϕ_{uk} (°)	c'_k (kN/m^2)	ϕ'_k (°)
Side Liner	20	50	0	5	23

Parameters Selected for Waste Analyses

2.19 The parameters of the inert waste appropriate for this site were selected on the basis of the information presented in the various publications listed in Table SRA5. As stated previously the inclusion of stratum specific references should not be taken as guidance to what may be included within the inert waste but purely as another source to help define a generic fine-grained material. In reality, it is likely to comprise a mixture of fine- and coarse-grained engineering soils and demolition materials. Therefore, the treatment of the inert waste as fine-grained will be the worst case as the inclusion of any coarse-grained material will increase its characteristic angle of shearing resistance.

Table SRA5: Waste Mass Stability - Summary of Characteristic Geotechnical Data

Material	Unit Weight	Total Stress		Effective Stress	
	γ_k (kN/m^3)	c_{uk} (kN/m^2)	ϕ_{uk} (°)	c'_k (kN/m^2)	ϕ'_k (°)
Waste Mass	17	50	0	10	25

Parameters Selected for Capping Analyses

2.20 None selected as no further analysis of the capping is required.

Selection of Appropriate Factors of Safety

2.21 The stability analyses have been carried out in accordance with EC7. The United Kingdom have adopted Design Approach 1 (DA1) Combination 1 & 2 (C 1 & 2) whereby partial factors are applied to either the actions or the material properties and a resultant factor of safety of 1.00 is required.

Table SRA6: Partial Factors used in Design in Accordance with the UK National Annex to EC7

Design Approach	Combination	Partial Factor Sets	Partial Factor Value			
1	1	A1 + M1 + R1	Actions A1			
			Permanent (G)	Unfavourable	$\gamma_{G;dst}$	1.35
				Favourable	$\gamma_{G;stb}$	1.00
			Variable (Q)	Unfavourable	$\gamma_{Q;dst}$	1.50
				Favourable	$\gamma_{G;dst}$	0
			Materials M1			
			Coefficient of shearing resistance ($tan\phi$)		$\gamma_{\phi'}$	1.00
			Effective cohesion (c')		$\gamma_{c'}$	1.00
			Undrained shear strength (c_u)		γ_{cu}	1.00
			Resistance R1			
			Resistance		$\gamma_{R;e}$	1.00
	2	A2 + M2 + R1	Actions A2			
			Permanent (G)	Unfavourable	$\gamma_{G;dst}$	1.00
				Favourable	$\gamma_{G;stb}$	1.00
			Variable (Q)	Unfavourable	$\gamma_{Q;dst}$	1.30
				Favourable	$\gamma_{G;dst}$	0
			Materials M2			
			Coefficient of shearing resistance ($tan\phi$)		$\gamma_{\phi'}$	1.25
			Effective cohesion (c')		$\gamma_{c'}$	1.25
			Undrained shear strength (c_u)		γ_{cu}	1.40
			Resistance R1			
			Resistance		$\gamma_{R;e}$	1.00

2.22 The values of the partial factors used are termed “nationally determined parameters” and EC7 (as published by CEN) allows these to be specified in National Annexes which recognise regional variations in design philosophy.

2.23 LFE4 – Earthworks in Landfill Engineering – Chapter 2 confirms the adoption of Design Approach 1 Combinations 1 and 2, and the nationally adopted partial factors.

Analyses

Side Slope Subgrade

2.24 Both the short- and long-term stability of the side slope subgrade have been assessed using the Slope/W software for a range of circular failures using total and effective stress parameters.

2.25 The analysis has included the placement and compaction of locally derived materials to reduce the gradient of the side slope subgrade to 1(V) : 2.5(H).

2.26 Results of the Side Slope Subgrade analyses are presented in Appendix 1 and summarised below.

Table SRA 7 Side Slope Subgrade Stability – Summary of Results

Run	File Name	Stress Condition	Factor of Safety		Notes
			C1	C2	
01	Side Slope 1	Effective	1.58		Side slope subgrade gradient reduced by the placement of Reworked locally derived materials (assumed reworked Lowestoft Formation.
02	Side Slope 2	Effective		1.26	
03	Side Slope 3	Effective	1.43		Groundwater rising from recorded value to 5m bgl
04	Side Slope 4	Effective		1.06	

Side Slope Liner

2.27 The side slope liner will be placed on the side slope subgrade after the gradient of the side slope subgrade has been reduced to 1(V) : 2.5(H). The side slope liner will comprise a minimum 1.00m thickness of imported low permeability clay.

2.28 The long- and short-term stability of the side slope liner has been analysed by considering total and effective stress conditions for both failures restricted to entirely within the liner and those which may affect both liner and subgrade.

2.29 The effects of long term softening of the side slope liner have been considered by reducing the effective cohesion of the liner material.

2.30 Results of the side liner analyses are presented in Appendix 2 and summarised below.

Table SRA 8 Side Slope Liner Stability – Summary of Results

Run	File Name	Stress Condition	Factor of Safety		Notes
			C1	C2	
05	Side Liner 1	Total	10.04		Failure restricted to Side Slope Liner only
06	Side Liner 2			9.76	
07	Side Liner 3	Effective	2.11		
08	Side Liner 4			1.88	

09	Side Liner 5	Effective		1.17	Softening of Side Slope Liner as a result of exposure to inclement weather
10	Side Liner 6	Effective	1.68		Failure within Side Slope Subgrade and Side Slope Liner
11	Side Liner 7	Effective		1.35	
12	Side Liner 8	Effective	1.34		Failure within Side Slope Subgrade and Side Slope Liner with rising Groundwater and softened Side Slope Liner
13	Side Liner 9	Effective		1.01	

Waste Mass Analyses

2.31 The maximum slopes of the waste during placement operations will be restricted to 1(V) : 2.5(H).

2.32 Leachate pore fluid pressures may develop in the waste mass during filling due to infiltration. It is noteworthy that the term leachate as applied refers to direct precipitation or groundwater present within the inert waste at time of placement.

2.33 Given the composition of the waste mass, landfill gas pressures are unlikely to develop within the waste mass.

2.34 Waste stability must be assessed as part of the design process for the temporary waste slope configuration. A Stability assessment is required for failure modes wholly within the waste body. The analyses of the failures wholly within the waste were based on Table 3.43 “Failure Wholly within the Waste” of the Environmental Agency R&D Technical Report P1-385/TR2.

2.35 Slope/W has been used to undertake the investigation into failures wholly within the waste mass for both total and effective stress conditions.

2.36 The effects of variations in leachate pressure were modelled by investigating the effects of increased leachate levels on the factor of safety against instability within the waste body.

2.37 Results of the analyses are presented in Appendix 3 and can be summarised as follows:

Table SRA9: Waste Mass Stability – Summary of Results

Run	File Name	Waste Strength	Leachate Level	Factor of Safety		Notes
				C1	C2	
14	Waste Mass 1	Total	Dry	2.01		Short term waste mass parameters
15	Waste Mass 2				1.93	
16	Waste Mass 3	Effective	2.00m	1.71		Increasing leachate level measured from
17	Waste Mass 4				1.44	

18	Waste Mass 5		4.00m	1.59		base of waste mass
19	Waste Mass 6					
20	Waste Mass 7		6.00m	1.49		
21	Waste Mass 8				1.12	
22	Waste Mass 9		Not Present	1.18		Cohesion = 0kN/m^2

Assessment

Basal Subgrade

2.38 The basal subgrade will comprise the in-situ Lowestoft Formation. The void will be created by the removal of the sands and gravels of the Lowestoft Formation which will lead to a net unloading of the Basal Subgrade whilst placement of the inert waste will reload it. Given the differences in the unit weights of the in-situ and placed materials there will be no increase in loading intensity on the Basal Subgrade. Therefore, settlements of the basal subgrade will be limited to the elastic recompression which will not affect the integrity of this in-situ material.

2.39 It is possible that in some areas that the Gault Formation may be exposed in the base of the void. The Gault Formation comprises a stiff grey clay which is competent and not subject to large settlements at the loading intensity under consideration. Therefore, the basal subgrade will remain stable and appropriate for the loading under consideration.

Side-Slope Subgrade

2.40 The side-slope subgrade will be formed by the extraction of the Lowestoft Formation. Cross sections, supplied by the Client, indicate the post extraction side slope subgrade at 1 (V) : 1 (H). Although stable in the short term the side slope Subgrade batter will be slackened to 1 (V) : 2.5 (H) by the placement of locally sourced materials.

2.41 All the side slope subgrade SlopeW analyses indicate that the Combination 2 partial factor set offers the more onerous of the two approaches recommended within the National Annex to EC7.

2.42 SlopeW runs 01 – 02 (Table SRA 7) indicate that the post mineral extraction slopes are stable at the new 1 (V): 2.5 (H) configuration with a minimum Factor of Safety of 1.26 being reported.

2.43 Groundwater monitoring has indicated that groundwater levels are below the base of the extraction void. However, to ensure a robust assessment, the affect of raising the groundwater to 5.00mbgl within the side slope subgrade has been undertaken. SlopeW runs 03 and 04 show a decrease in factor of safety from those recorded in the dry side slope subgrade analyses but remain above the target value of 1.00 (1.43 and 1.06).

2.44 Based on the results of the analyses, it is concluded that the side slope subgrade will be stable at heights of up to 11.00m provided the side slope gradient does not exceed 1(V) : 2.5(H) (22˚).

Side-Slope Liner

Failure along interface with subgrade

2.45 Failures of side slope liner have been modelled using the SlopeW software to calculate the factor of safety against instability occurring along the interface with the side slope subgrade and within the side slope liner and subgrade.

2.46 When considering failure along the interface with the side slope subgrade both short- and long-term stability has been considered and indicate that in undrained condition the liner is stable with a minimum factor of safety of 9.76 being returned under Design Approach 1 Combination 2 factoring.

2.47 In the long term under effective stress conditions the side slope liner remains stable with a lowest factor of safety of 1.88 being achieved under Design Approach 1 Combination 2 factoring.

2.48 To model long term softening of the side slope liner the effective cohesion was reduced to 1kN/m^2. Even under this onerous and unlikely condition a serviceability limit state analysis returned a factor of safety of 1.17.

Failure through side slope liner and subgrade

2.49 To analyse the affect of placement of the side-slope liner on the side-slope subgrade a further two effective stress analyses have been carried out with the shear plane free to form within and cross between both materials. SlopeW runs 10 and 11 return Factors of Safety of 1.68 and 1.35 under Design Approach 1 Combination 1 and 2 factoring respectively.

2.50 Finally, SlopeW runs 12 and 13 demonstrate the long-term stability of the combined side-slope subgrade and liner under worst-case conditions with groundwater at 5.00mbgl and softened side liner. Even under these onerous conditions the returned factors of safety remain above the target value of 1.00

2.51 The side slope lining system is considered appropriate provided the face angle does not exceed 1(V) : 2.5(H) and a minimum perpendicular thickness of 1.00m is maintained. Although the analyses indicate the long-term stability of the full-height liner; it remains good engineering practice to minimise the amount of time the liner is left exposed to prior to the placement of waste.

Waste Mass

2.52 The stability of the temporary waste face was analysed using the computer programme SLOPE/W to calculate the factor of safety against failure through the waste body for a range of circular failure surfaces using Morgenstern and Price's method.

2.53 The importance of different leachate levels within the waste and their effect on overall stability were assessed. The effect of reduction of shear strength from peak to residual values has also been investigated.

2.54 The waste slope has a factor of safety > 1 for all leachate levels including the unlikely situation where 6.00m of leachate accumulates in the waste mass.

2.55 The waste slope has a factor of safety of 1.18 even if the value of the cohesion intercept of the waste reduces from 10kN/m^2 to 0kN/m^2.

2.56 It is concluded that a 1(V) : 2.5(H) waste slope will be stable for the range of leachate levels anticipated.

3.0 MONITORING

The Risk-Based Monitoring Scheme

3.1 Monitoring of the stability of the site is proposed in the form set out below. The objectives are to identify any instances of overall settlement of the structure in excess of that expected from the settlement predictions, and to identify instability of the waste mass itself at the earliest possible juncture.

Basal Subgrade Monitoring

3.2 During the mineral extraction works, prior to the placement of the basal liner, it is recommended that continuous monitoring of the subgrade is carried out with respect to the competency and identification of local soft spots. In the unlikely event that the Gault Clay Formation is exposed in the base of the void softening of this formation may be expected if left exposed for long periods.

3.3 If either of the conditions described above are identified. the softened material should be excavated and replaced by appropriately compacted granular fill prior to the placement of the basal liner.

Basal Liner

3.4 Visual monitoring of the basal liner should be routinely undertaken prior to the placement of the inert waste. If any cracking or subsidence is identified the basal liner should be excavated and the basal subgrade inspected and replaced as necessary.

Side Slope Subgrade + Lining Monitoring

3.5 The side slopes should be visually monitored for instability both during the extraction works and waste placement operations. In the event of any instances of instability appropriate action should be taken which may include buttressing the toe of the slope using inert waste material or reducing the side slope angle.

3.6 After placement of the side slope liner regular visual inspection should be carried out to ensure no softening of the liner material is occurring. Local bulges should be reported immediately as this could be indicative of a build-up of hydrostatic forces behind the liner. If such anomalies are identified the liner should be buttressed by the placement of inert waste to balance out the hydrostatic forces.

Waste Mass Monitoring

3.7 The temporary slopes in the waste should be visually monitored and appropriate actions taken on any sign of instability. This would typically include a reduction in slope angle of the temporary waste slopes.

Capping System Monitoring

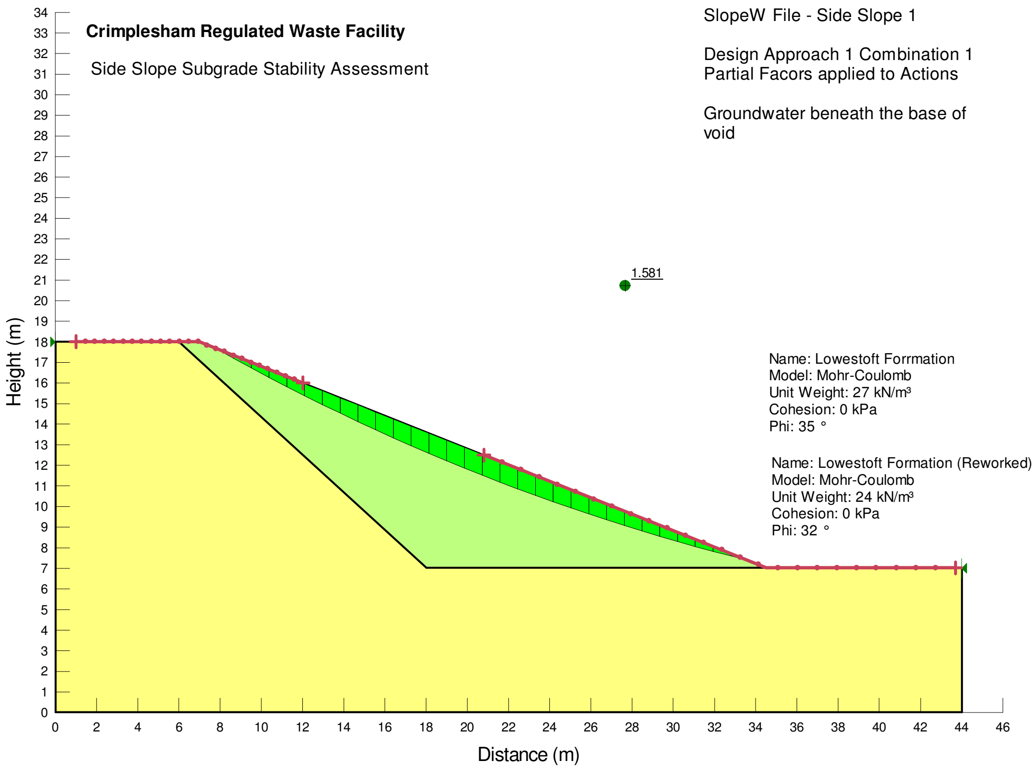
3.8 The condition of the surface of all capped and/or restored areas will be monitored on a regular basis as part of the site inspection regime.

3.9 The surface will be checked for incipient signs of failure that might result from the occurrence of differential settlement within these deposits. These would include cracking, development of depressions or ponding and seepage of water.

3.10 The Surface of the restored areas will be monitored by land survey techniques on a regular basis. These checks will be on a biannual basis for the first two years and then on an annual basis to the fifth year after restoration, when the periodicity can be reviewed with the Environment Agency.

Appendix 1

Slope/W Worksheets – Side Slope Subgrade



Crimplesham Regulated Waste Facility

Side Slope Subgrade Stability Assessment

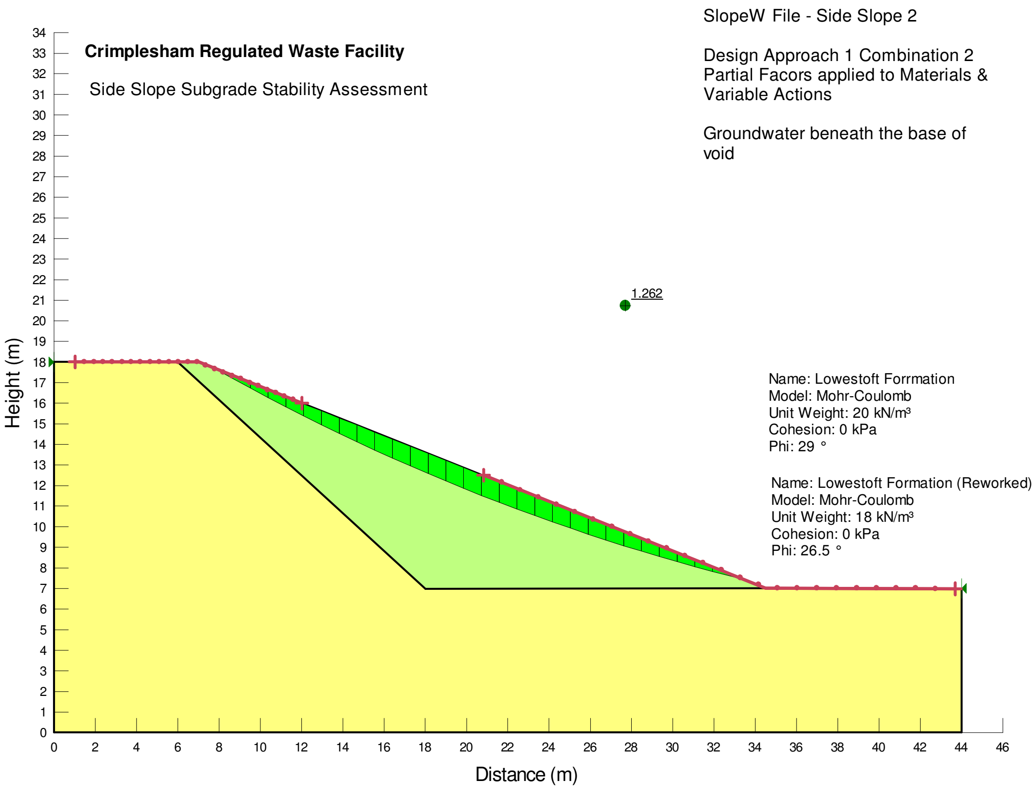
SlopeW File - Side Slope 1

Design Approach 1 Combination 1
Partial Facors applied to Actions

Groundwater beneath the base of void

Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 27 kN/m^3
Cohesion: 0 kPa
Phi: 35 °

Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 24 kN/m^3
Cohesion: 0 kPa
Phi: 32 °



Crimplesham Regulated Waste Facility

Side Slope Subgrade Stability Assessment

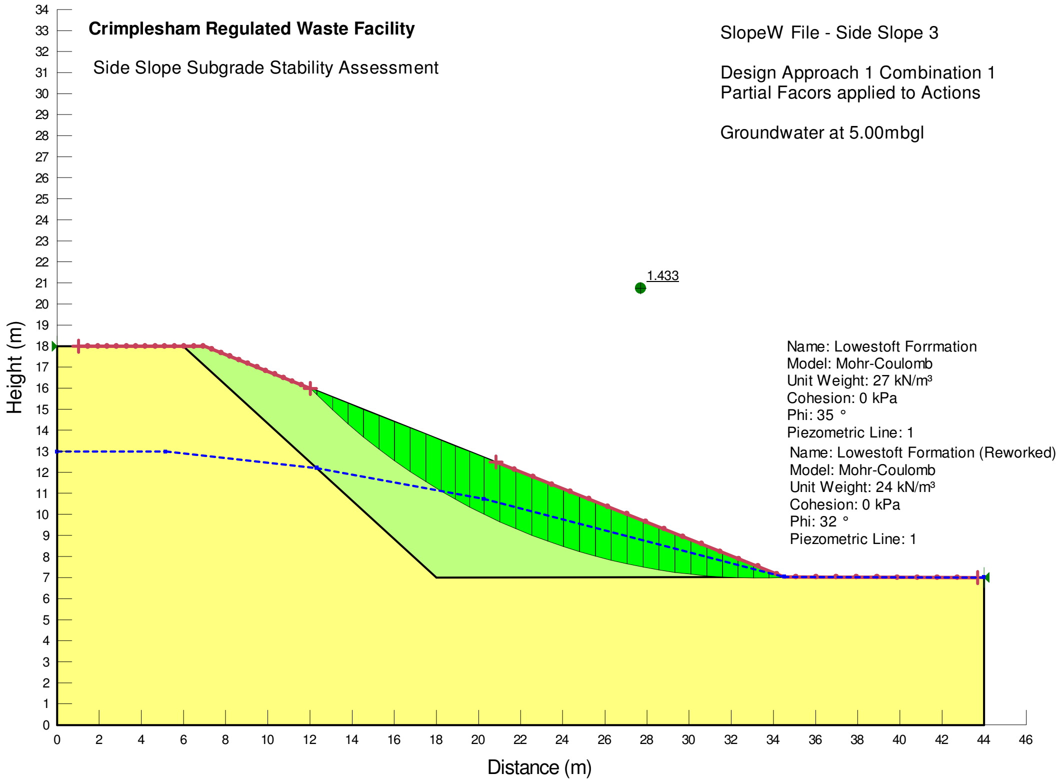
SlopeW File - Side Slope 2

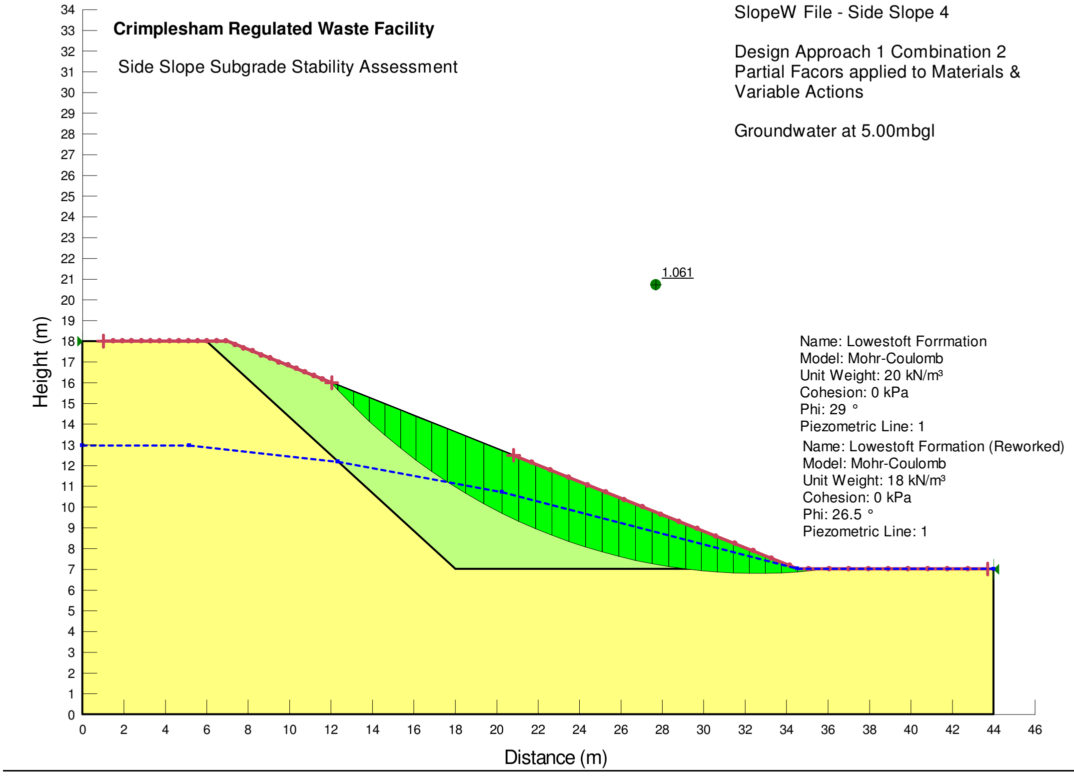
Design Approach 1 Combination 2
Partial Facors applied to Materials & Variable Actions

Groundwater beneath the base of void

Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 20 kN/m^3
Cohesion: 0 kPa
Phi: 29 °

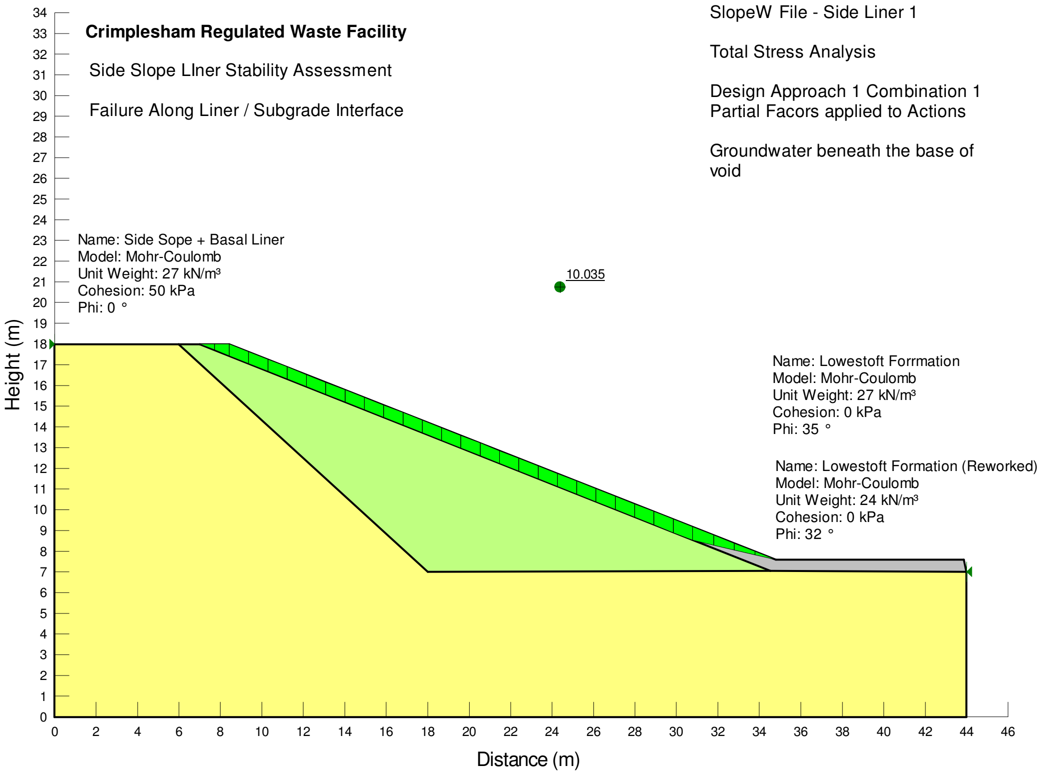
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 18 kN/m^3
Cohesion: 0 kPa
Phi: 26.5 °

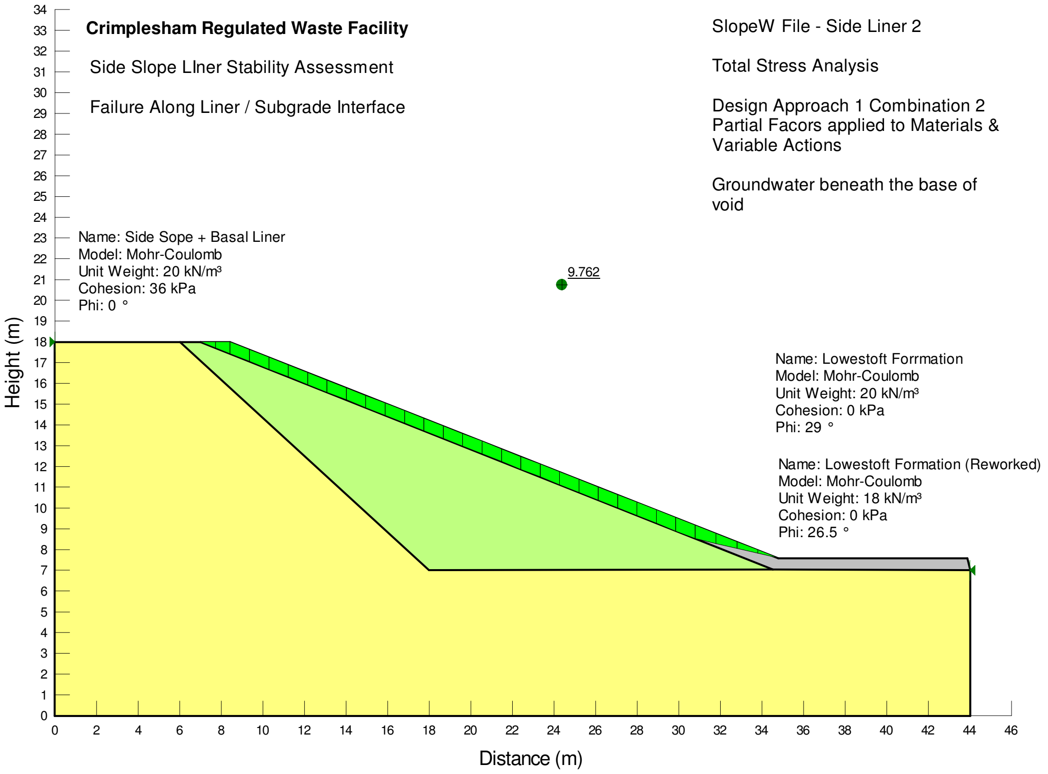

Crimplesham Regulated Waste Facility
Side Slope Subgrade Stability Assessment
SlopeW File - Side Slope 3
Design Approach 1 Combination 1
Partial Facors applied to Actions
Groundwater at 5.00mbgl
1.433
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Piezometric Line: 1
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 24 kN/m³
Cohesion: 0 kPa
Phi: 32 °
Piezometric Line: 1
Height (m)
Distance (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46

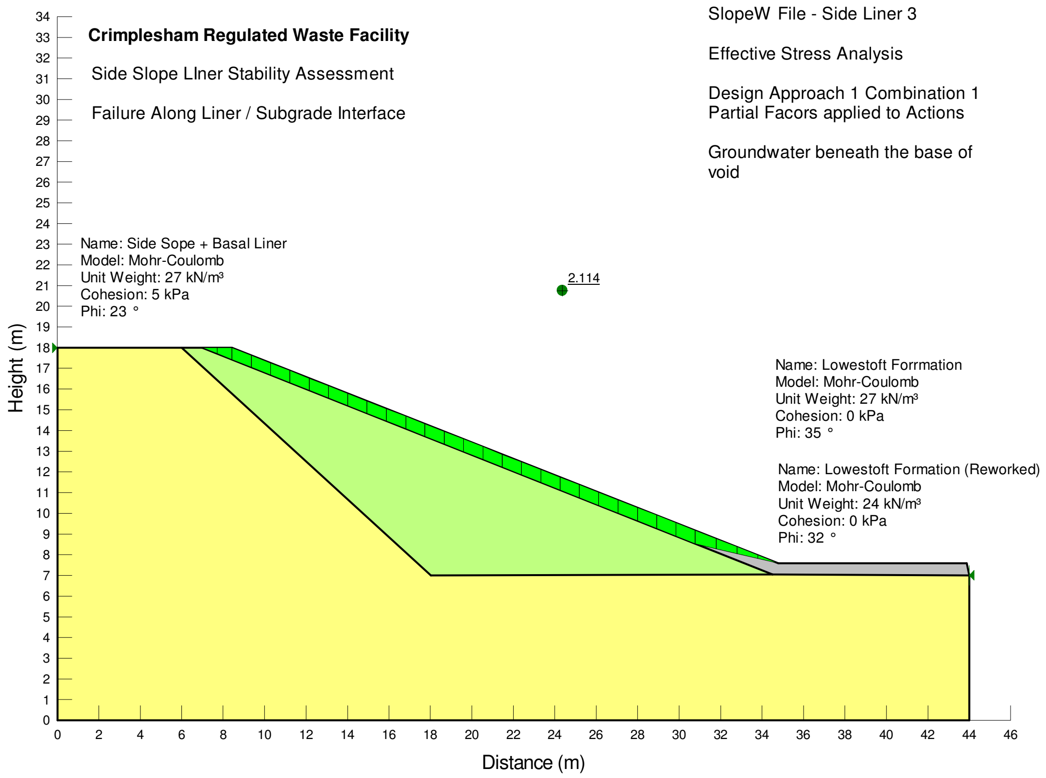

Crimplesham Regulated Waste Facility
Side Slope Subgrade Stability Assessment
SlopeW File - Side Slope 4
Design Approach 1 Combination 2
Partial Facors applied to Materials &
Variable Actions
Groundwater at 5.00mbgl
1.061
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: 29 °
Piezometric Line: 1
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion: 0 kPa
Phi: 26.5 °
Piezometric Line: 1
Height (m)
Distance (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46

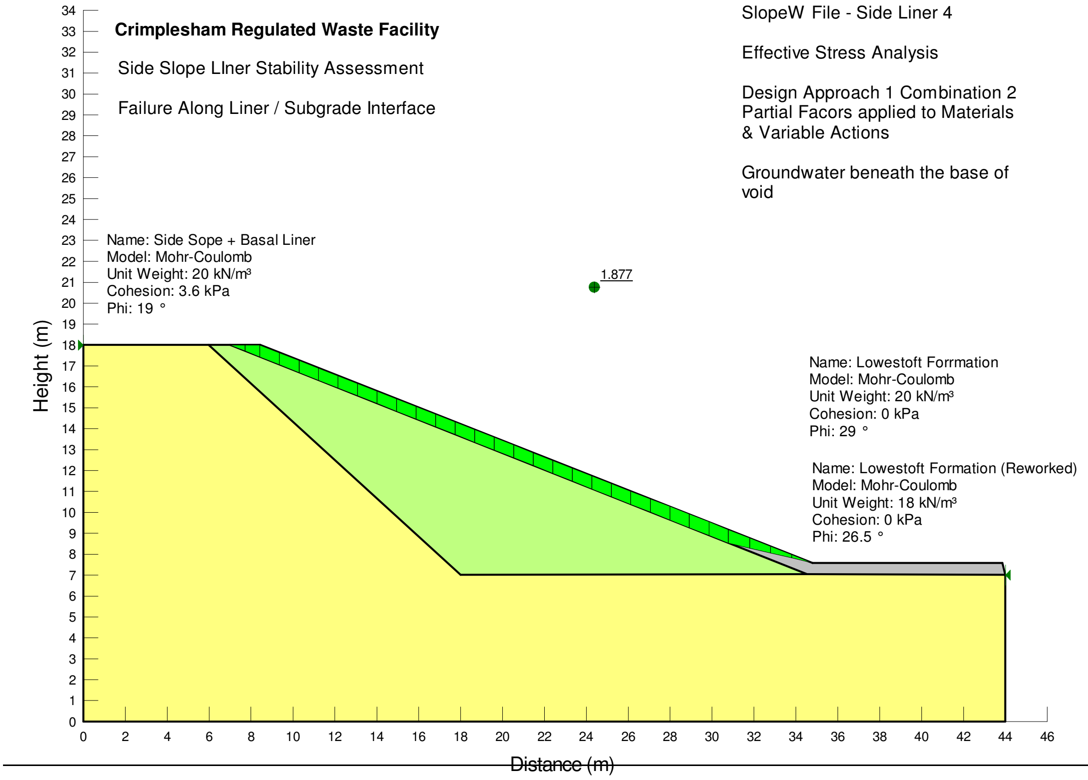
Appendix 2

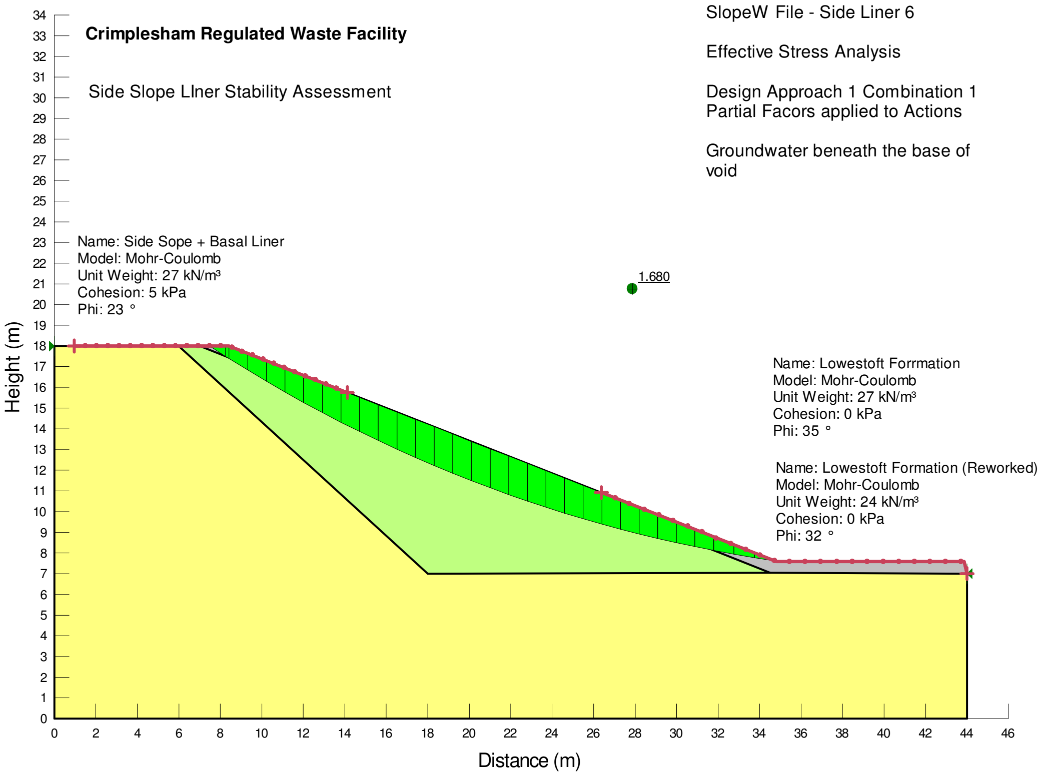
Slope/W Worksheets – Side Slope Liner

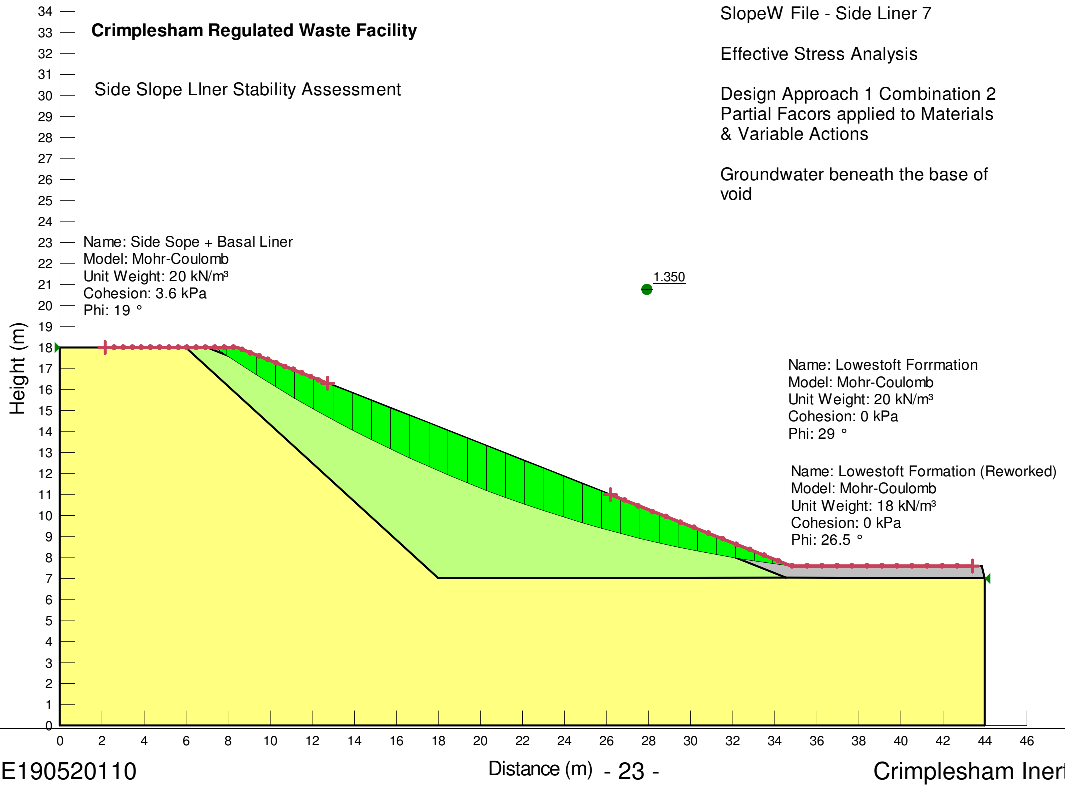

Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
Failure Along Liner / Subgrade Interface
SlopeW File - Side Liner 1
Total Stress Analysis
Design Approach 1 Combination 1
Partial Facors applied to Actions
Groundwater beneath the base of void
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 50 kPa
Phi: 0 °
10.035
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 24 kN/m³
Cohesion: 0 kPa
Phi: 32 °
Height (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Distance (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46

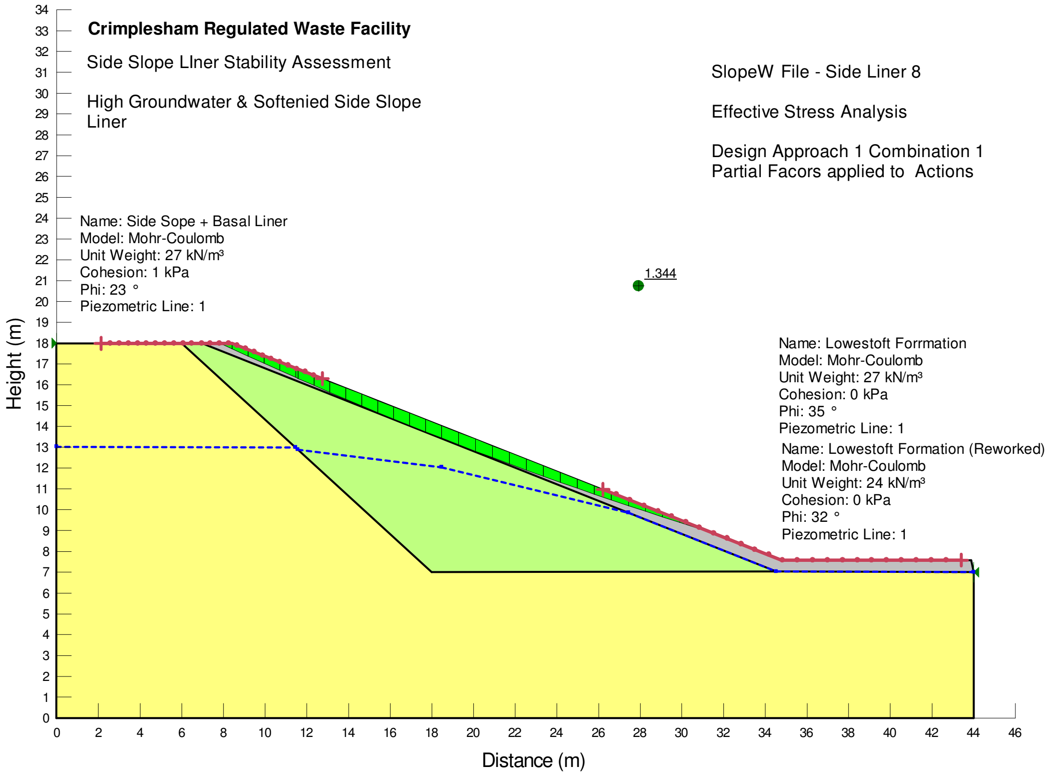

Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
Failure Along Liner / Subgrade Interface
SlopeW File - Side Liner 2
Total Stress Analysis
Design Approach 1 Combination 2
Partial Facors applied to Materials & Variable Actions
Groundwater beneath the base of void
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 36 kPa
Phi: 0 °
9.762
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: 29 °
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion: 0 kPa
Phi: 26.5 °
Height (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Distance (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46

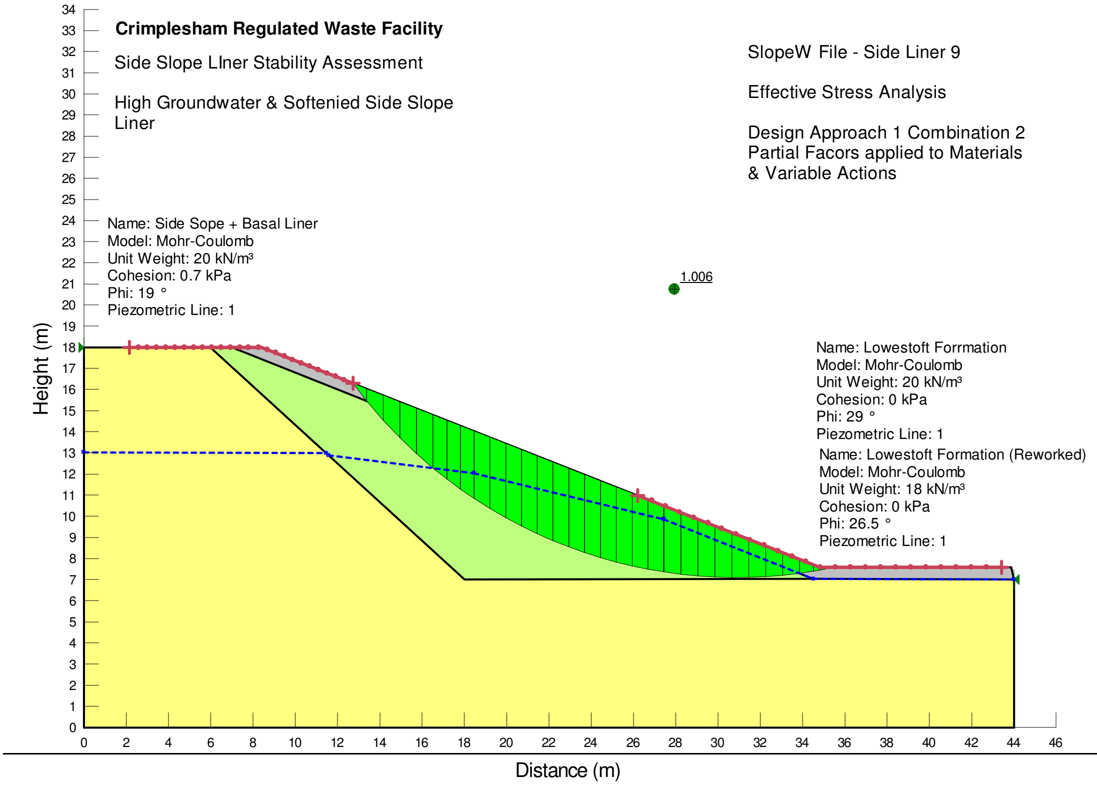

Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
Failure Along Liner / Subgrade Interface
SlopeW File - Side Liner 3
Effective Stress Analysis
Design Approach 1 Combination 1
Partial Facors applied to Actions
Groundwater beneath the base of void
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 5 kPa
Phi: 23 °
2.114
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 24 kN/m³
Cohesion: 0 kPa
Phi: 32 °
Height (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Distance (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46


Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
Failure Along Liner / Subgrade Interface
SlopeW File - Side Liner 4
Effective Stress Analysis
Design Approach 1 Combination 2
Partial Facors applied to Materials & Variable Actions
Groundwater beneath the base of void
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 3.6 kPa
Phi: 19 °
1.877
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: 29 °
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion: 0 kPa
Phi: 26.5 °
Height (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Distance (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46


Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
SlopeW File - Side Liner 6
Effective Stress Analysis
Design Approach 1 Combination 1
Partial Facors applied to Actions
Groundwater beneath the base of void
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 5 kPa
Phi: 23 °
1.680
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 24 kN/m³
Cohesion: 0 kPa
Phi: 32 °
Height (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Distance (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46

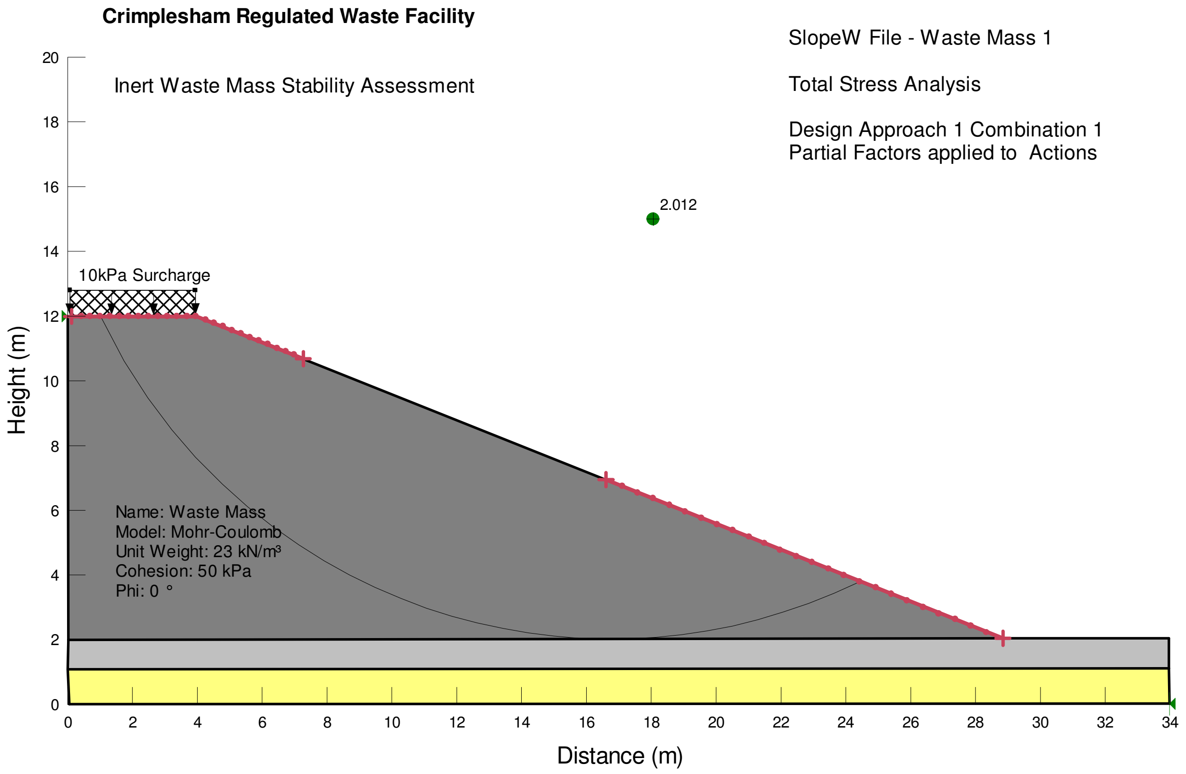

Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
SlopeW File - Side Liner 7
Effective Stress Analysis
Design Approach 1 Combination 2
Partial Facors applied to Materials & Variable Actions
Groundwater beneath the base of void
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 3.6 kPa
Phi: 19 °
1.350
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: 29 °
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion: 0 kPa
Phi: 26.5 °
Height (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Distance (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46

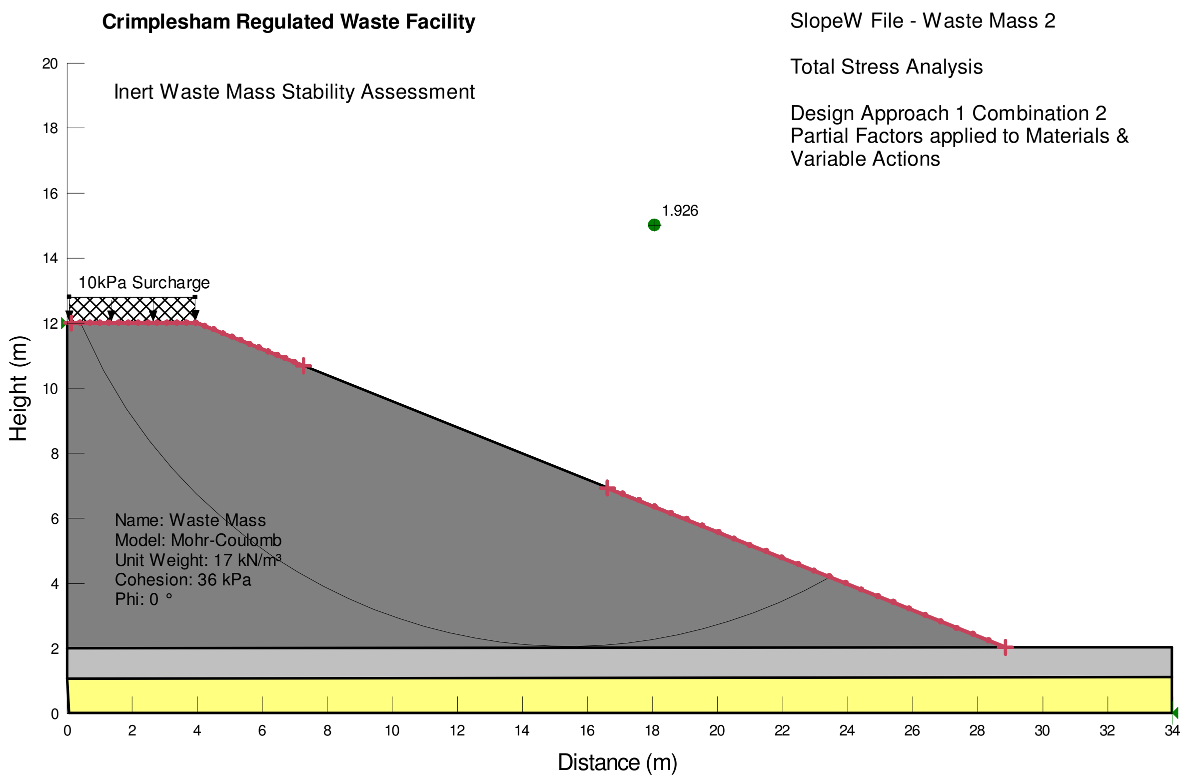

Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
High Groundwater & Softenied Side Slope Liner
SlopeW File - Side Liner 8
Effective Stress Analysis
Design Approach 1 Combination 1
Partial Facors applied to Actions
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 1 kPa
Phi: 23 °
Piezometric Line: 1
1.344
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 27 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Piezometric Line: 1
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 24 kN/m³
Cohesion: 0 kPa
Phi: 32 °
Piezometric Line: 1
Height (m)
Distance (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46


Crimplesham Regulated Waste Facility
Side Slope LIner Stability Assessment
High Groundwater & Softenied Side Slope Liner
SlopeW File - Side Liner 9
Effective Stress Analysis
Design Approach 1 Combination 2
Partial Facors applied to Materials & Variable Actions
Name: Side Sope + Basal Liner
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0.7 kPa
Phi: 19 °
Piezometric Line: 1
1.006
Name: Lowestoft Forrmation
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: 29 °
Piezometric Line: 1
Name: Lowestoft Formation (Reworked)
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion: 0 kPa
Phi: 26.5 °
Piezometric Line: 1
Height (m)
Distance (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46

Appendix 3

Slope/W Worksheets – Waste Mass

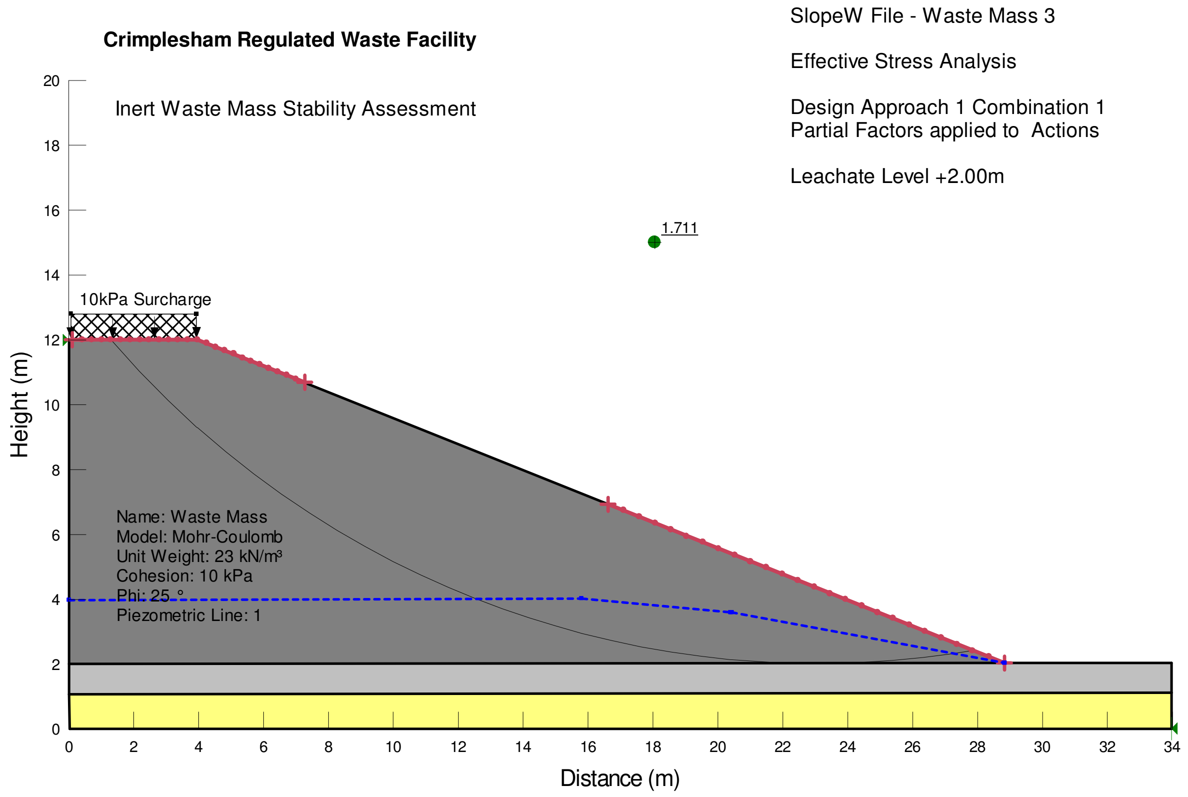

Crimplesham Regulated Waste Facility
Inert Waste Mass Stability Assessment
SlopeW File - Waste Mass 1
Total Stress Analysis
Design Approach 1 Combination 1
Partial Factors applied to Actions
2.012
10kPa Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 23 kN/m³
Cohesion: 50 kPa
Phi: 0 °
Height (m)
Distance (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34



SlopeW File - Waste Mass 2

Total Stress Analysis

Design Approach 1 Combination 2
Partial Factors applied to Materials &
Variable Actions

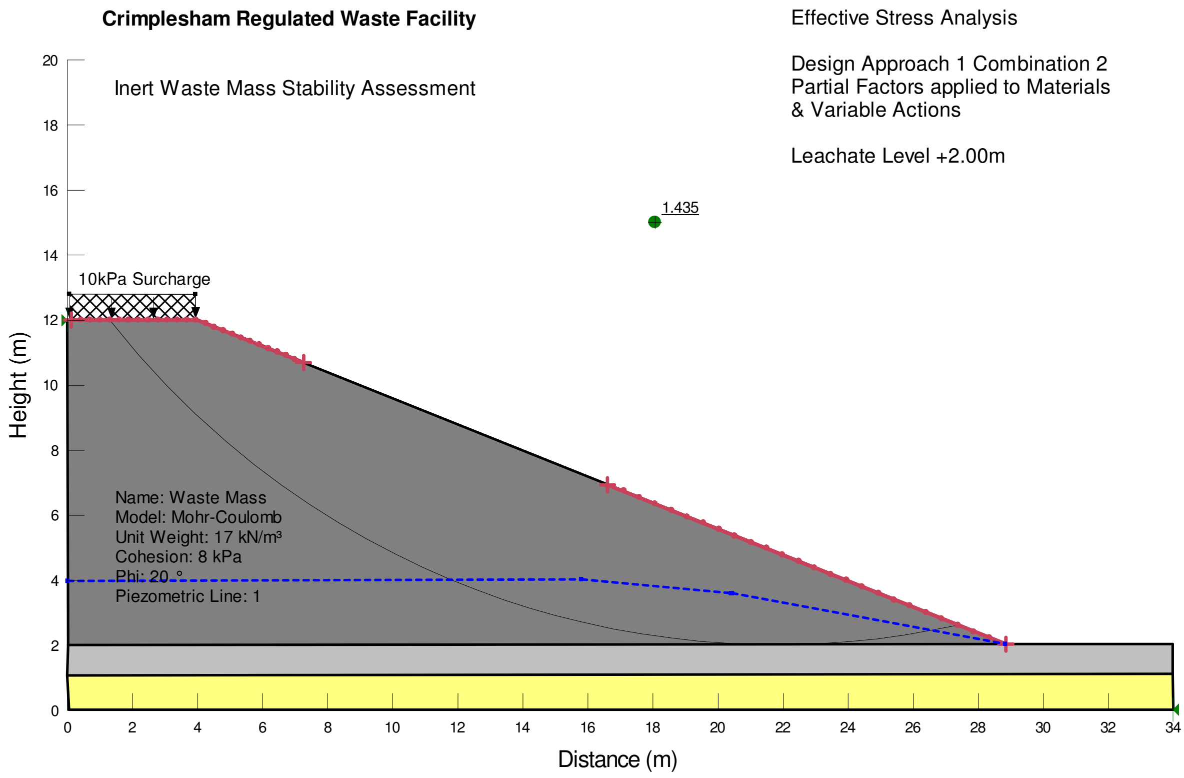


SlopeW File - Waste Mass 3

Effective Stress Analysis

Design Approach 1 Combination 1
Partial Factors applied to Actions

Leachate Level +2.00m

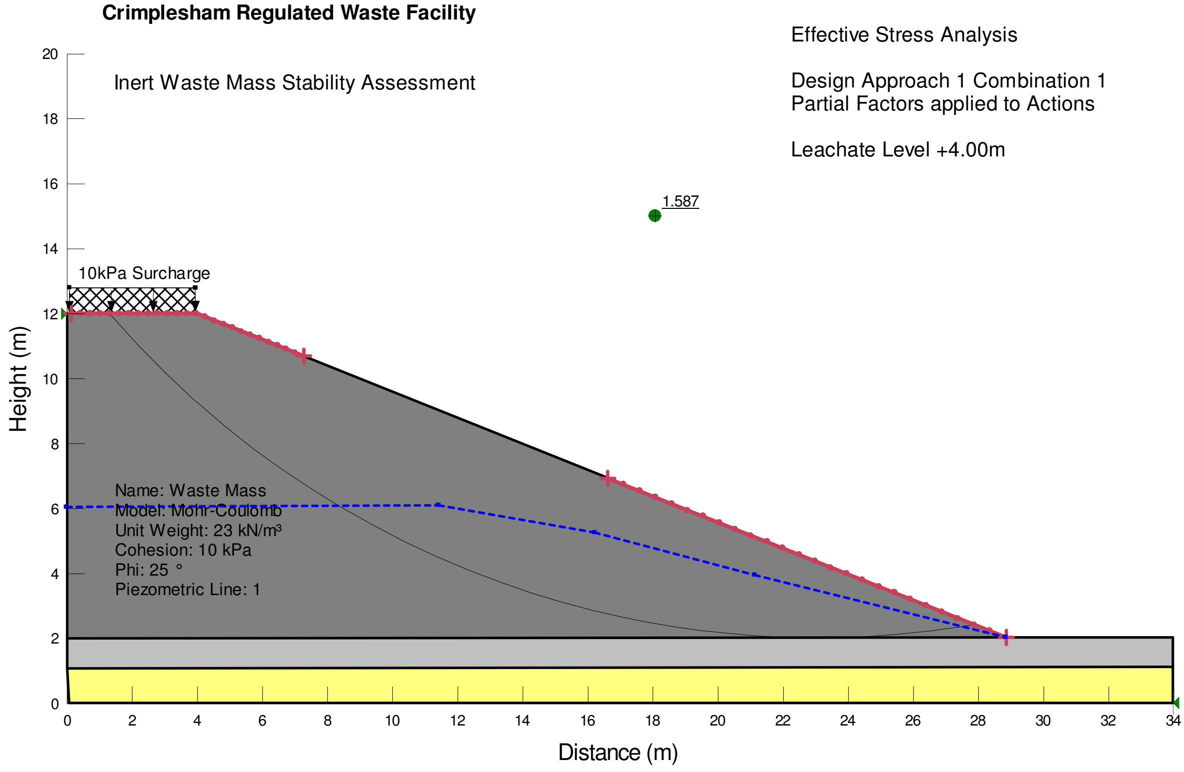


SlopeW File - Waste Mass 4

Effective Stress Analysis

Design Approach 1 Combination 2
Partial Factors applied to Materials
& Variable Actions

Leachate Level +2.00m

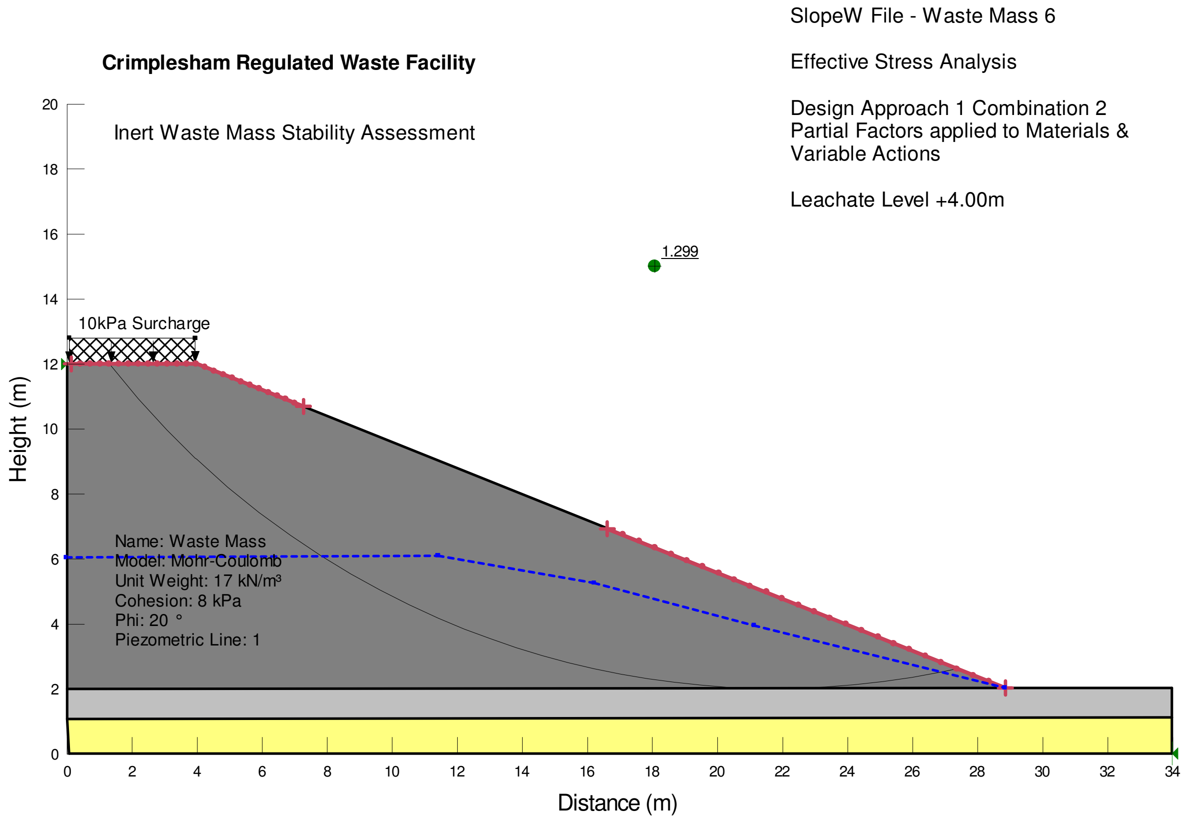


SlopeW File - Waste Mass 5

Effective Stress Analysis

Design Approach 1 Combination 1
Partial Factors applied to Actions

Leachate Level +4.00m

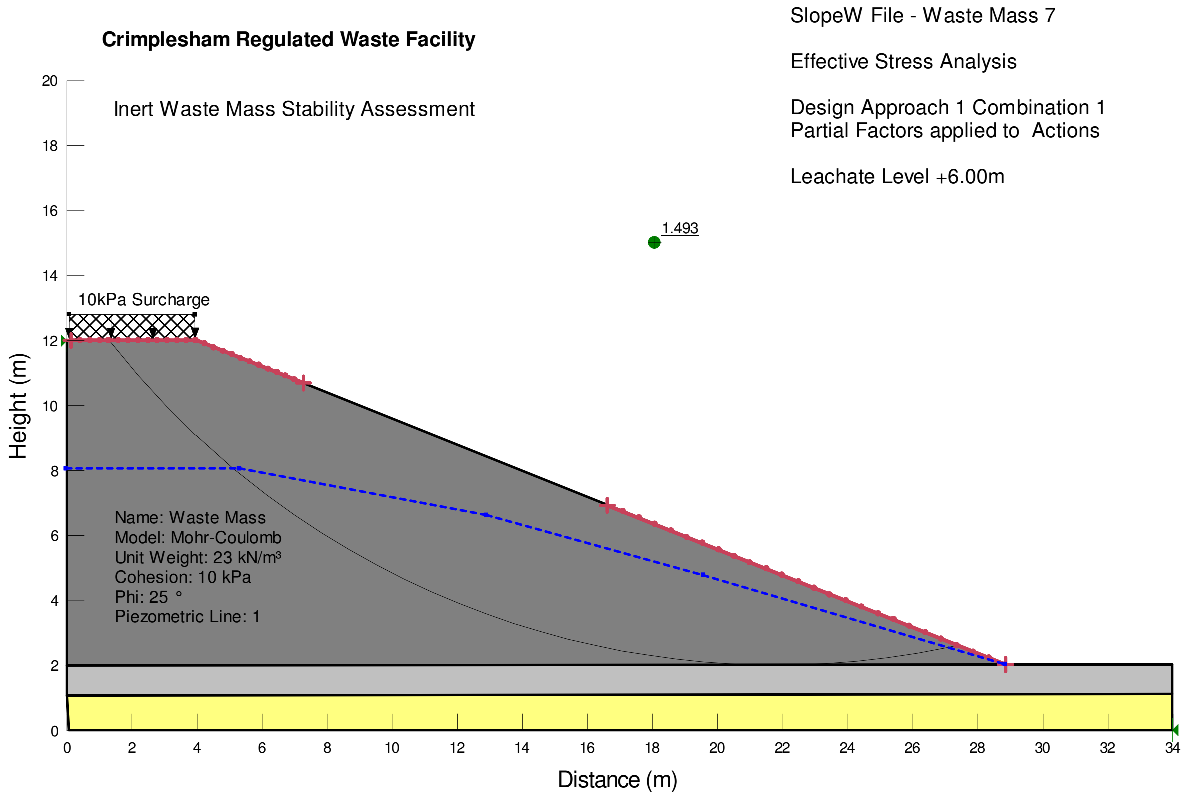


SlopeW File - Waste Mass 6

Effective Stress Analysis

Design Approach 1 Combination 2
Partial Factors applied to Materials &
Variable Actions

Leachate Level +4.00m



SlopeW File - Waste Mass 7

Effective Stress Analysis

Design Approach 1 Combination 1
Partial Factors applied to Actions

Leachate Level +6.00m

Crimplesham Regulated Waste Facility

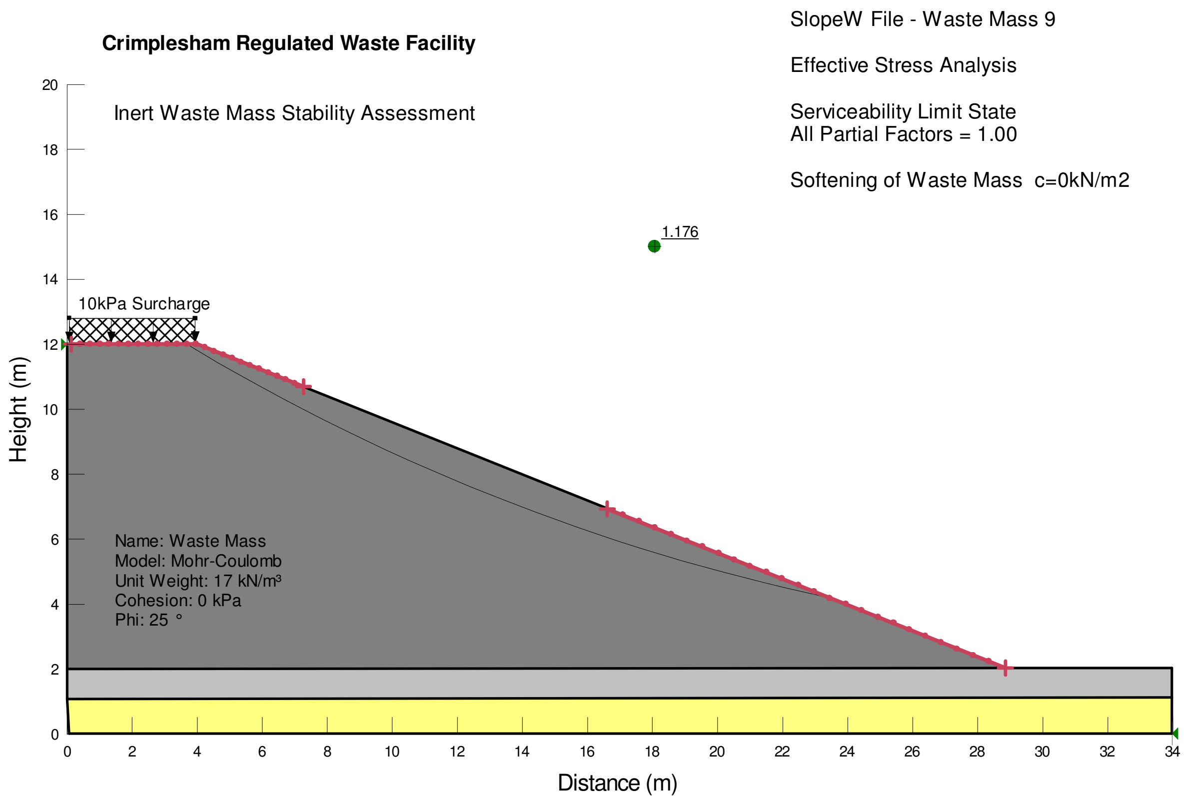
Inert Waste Mass Stability Assessment

SlopeW File - Waste Mass 8

Effective Stress Analysis

Design Approach 1 Combination 2
Partial Factors applied to Materials &
Variable Actions

Leachate Level +6.00m



Crimplesham Regulated Waste Facility

Inert Waste Mass Stability Assessment

SlopeW File - Waste Mass 9

Effective Stress Analysis

Serviceability Limit State
All Partial Factors = 1.00

Softening of Waste Mass c=0kN/m2