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# TETRA TECH LTD.

## GREETHAM INERT LANDFILL

## ENVIRONMENTAL PERMIT APPLICATION

## Stability Risk Assessment Report V1

## GEC NO: GE200222805

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| | | |

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# 1.0 INTRODUCTION

## Report Context

1.1 The operator of the installation is Mick George Ltd. (MGL).

1.2 Tetra Tech have instructed Geotechnical & Environmental Consulting Ltd. (GEC) to undertake a Stability Risk Assessment (SRA) to form part of an Environmental Permit Variation Application for Greetham Quarry Inert Landfill.

1.3 This environmental permit application is for the permanent placement of inert material within the void formed by the extraction of minerals.

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

- Greetham Quarry Inert Landfill, Permit Application, Environmental Setting and Site Design – Tetra Tech Report No B027573 – July 2022.
- Greetham Quarry Inert Landfill, Operating Techniques – Tetra Tech Report No B027573 – July 2022.
- Greetham Quarry Inert Landfill, Hydrogeological Risk Assessment – Tetra Tech Report No B027573 – July 2022.
- This Report has been completed in conjunction with the Environmental Setting and Site Design Report (ESSD) (July 2022.). 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.

1.5 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 MGL- B027573-PER-01 of the Environmental Setting and Site Design Report and covers the area known as Greetham Quarry.

1.7 The application site is located on a parcel of land adjacent to the existing Greetham Quarry and is located on the northern boundary of the village of Greetham and 1.75 kilometres (km) southwest of the village of Stretton. The site is centred at National grid Reference (NGR) SK 92941 15078 and the environmental permit boundary is shown on MGL/B027573/PER/01.

## Regional Geology

*Solid Geology*

1.8 Please refer to the most recent Hydrogeological Risk Assessment for this application (July 2022) for a more detailed description of the geology in and around the site. However, the below gives a shortened version.

1.9 With reference to British Geological Survey there is no recorded superficial geology for the majority of the site, however the north and north east boundary of the site is underlain by Till, Mid Pleistocene (Diamicton). These superficial deposits were formed up to 2 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions.

1.10 The bedrock geology for the southern side of the site is Lower Lincolnshire Limestone Member. The northern side of the site is underlain on Upper Lincolnshire Limestone Member. This sedimentary bedrock formed approximately 168 to 170 million years ago in the Jurassic Period. Local environment previously dominated by shallow carbonate seas.

1.11 The Lower Lincolnshire Limestone Member is described as limestones, dominated by low-energy calcilutite, and peloidal wackestone and packstone. Commonly includes sandy limestone or calcareous sandstone in basal part (locally known as Collyweston Slate).

## Local Geology

1.12 6No. boreholes records are available from the British Geoscience Database for drilling works which have been undertaken within the site boundary. The stratigraphy recorded in these boreholes is rudimentary it has been interpreted and presented in Table SRA1.

**Table SRA 1 Stratigraphy Recorded in Local Boreholes**

| BGS BH No. | NGR | Stratigraphy | | | |
|---|---|---|---|---|---|
| | | Topsoil / Made Ground | | Lincolnshire Limestone Formation | |
| | | From (mbgl) | Thickness (m) | From (mbgl) | Thickness (m) |
| BH1 | 493916,297854 | GL | 0.40 | 0.40 | 11.60 |
| BH2 | 494285,297491 | GL | 2.50 | 2.50 | 11.50 |
| BH3 | 494642,297454 | GL | 0.30 | 7.80 | 13.20 |
| BH4 | 495035,297952 | GL | 0.90 | 8.10 | 13.30 |
| BH5 | 494285,297491 | GL | 2.50 | 2.50 | 11.50 |

| | | | | | |
|---|---|---|---|---|---|
| BH6 | 494510,298123 | GL | 0.6 | 97.65 | 13.1 |

1.13 The full thickness of the Lincolnshire Limestone Formation (LLF) was encountered in all exploratory boreholes summarised in Table SRA1. The LLF attained proven thicknesses of 8.53 to 17.98m and comprised interbedded soft and hard limestone with yellow sand horizons.

1.14 Groundwater was encountered during the installation of the 4No. monitoring wells (Table SRA 2).

**Table SRA2: Groundwater Strikes during the Installation of the Groundwater Monitoring Wells**

| Borehole ID | Water Strike | | Strata Descriptions |
|---|---|---|---|
| | mbgl | mAOD | |
| BH1 | 5.80 | 95.50 | Lincolnshire Limestone Formation |
| BH2 | 6.00 | 95.38 | Lincolnshire Limestone Formation |
| BH3 | 12.50 | 91.29 | Lincolnshire Limestone Formation |
| BH4 | none | none | Lincolnshire Limestone Formation |
| BH5 | 18.40 | 84.47 | Lincolnshire Limestone Formation |
| BH6 | none | none | - |

Hydrology

1.15 According to the Flood Map for Planning Service (FMPS) and the Amber Planning Flood Risk Assessment produced, this is located in Flood Zone 1 which has a low probability of flooding.

1.16 The site is located within the catchment of North Brook a tributary of the River Gwash. North Brook flows west to east approximately 75m south of the existing quarry boundary and approximately 220m south of the proposed extension area. There are no other open surface water features in the vicinity of the proposed development area.

Hydrogeology

1.17 With reference to the Multi Agency Geographic Information for the Countryside's (MAGIC) website under the Groundwater Vulnerability Map, the site is situated within an area of High vulnerability and lies in a Source Protection Zone 2. Zone 2 (Outer Protection Zone) is defined by the 400-day travel time from a point below the water table.

1.18 In terms of aquifers, the MAGIC website shows that the site overlies a Principal Aquifer. The existing quarry also overlies the same Principal Aquifer.

1.19 Cross-sections through the landfill are presented in the Hydrological Risk Assessment and are reproduced herein and presented as Appendix 1.

## Basal Subgrade Model

1.20 The void will be created by the extraction of the Lincolnshire Limestone Formation.

## Basal Lining System

1.21 A full basal lining system will be required.

1.22 Locally sourced material will be used to create a basal liner 0.5m thick with a permeability of $5x10^{-8}$m/s or its equivalent a 1m liner with a permeability of $1x10^{-7}$m/s.

## Side Slope Subgrade Model

1.23 The side slope subgrade will be exposed during the mineral extraction works, which will be carried out by MGL and will comprise Lincolnshire Limestone Formation with imported CL:AIRE material acting as fill to create side slopes where necessary.

1.24 The LLF is likely to stand unsupported at near vertical angles dependant on the distribution of discontinuities within the rock mass and their effect on the kinematic stability of the rock faces.

1.25 Mineral extraction works commenced in April 2019 and no groundwater inflow into the void has been reported. Dewatering has not been required to enable the extraction of the mineral resource and is not thought to be required for the subsequent landfilling operations. It should also be noted that MGL have experience from a number of operational quarries in this area to indicate that if any groundwater is encountered it will be in the form of small weeps onto the face of the excavation which will not need any remedial action and will not need any dewatering. If any groundwater weeps are encountered the local EA officer dealing with the CQA plan will be invited to the site examine the situation for themselves.

1.26 If at that time the local EA officer considers that the groundwater ingress is sufficient to warrant management, groundwater control measures will be discussed and then put in place. As an example, this could include the installation of drainage pipework at the base of the side wall that would collect any groundwater ingress and channel it to a collection point where it can be pumped away from the area. Any such agreed management controls would also be added to the CQA plan for the site.

1.27 Cross sections through the side slope subgrade are presented in MGL-B027573-HYD-01.

## Side Slope Lining Model

1.28 It is likely that the side slope lining will be placed in stages as the waste level rises such that side slope lining is not left unsupported for long periods of time before being buttressed by the inert waste.

1.29 The side slope liner will comprise a geological barrier 1m thick with a minimum hydraulic conductivity of less than $1.0 \times 10m^{-7}$ m/s or its equivalent 0.5m thick with a hydraulic conductivity of $5.0 \times 10^{-8}$ m/s.

## Inert Waste Mass Model

1.30 It is proposed that Greetham Quarry will be used for the placement of inert waste only.

1.31 The inert waste is liable to comprise locally derived arisings from earthworks, foundation construction works and demolition debris.

1.32 The geology of the local area is variable and comprises both coarse- and fine-grained materials. As most of the inert waste is likely to comprise locally derived materials. With respect to stability the worst case would be a 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 SRA3: 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 2$^{nd}$. 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.*

1.33 The maximum temporary waste slope during placement operations will be restricted to 1(v):3(h).

1.34 The waste will be compacted in horizontal layers across the base of the cell to the pre-settlement restoration level.

## Capping System Model

1.34 On completion of filling to final levels, the site will be capped with 1m of restoration soils comprising not less than 0.3m of topsoil. In accordance with the requirements of the Landfill Directive, an engineered cap (clay or plastic) is not required.

## 2.0 STABILITY RISK ASSESSMENT

### Risk Screening

Basal Subgrade Screening

2.1 The basal subgrade will be formed of the in-situ Lincolnshire Limestone Formation. As the void will be formed by the excavation and extraction of material there will be a net unloading of the ground. 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.

2.2 No stability analysis of this component is considered necessary.

Basal Lining System Screening

2.3 The basal liner is to comprise locally sourced fine-grained material which will be placed as either 1.00m of clay with a hydraulic conductivity of $1.0 \times 10^{-7}$m/s or its equivalent of 0.5m of clay with a hydraulic conductivity of $5.0 \times 10^{-8}$m/s. The basal lining will be across the whole of the site but will obviously not be constructed as a single entity and will be built in stages.

2.4 Based on direct observation of conditions during the current mineral extraction operations and information presented in the Hydrogeological Risk Assessment (HRA) dated July 2022, in particular the distinct lack of groundwater outflow from the Lincolnshire Limestone Formation and depth of the groundwater within the Northampton Sand Formation, uplift on the underside of the basal liner is not considered a possibility or a risk at this site. Therefore, no further analyses of the basal layer are considered necessary.

Side Slope Subgrade Screening

2.5 The side slopes will be formed as part of the mineral extraction process carried out by MGL and be subject to geotechnical appraisal under Regulation 33 of the Quarries Regulations. It can therefore be assumed that the void will have been designed to be stable during the extraction works. Given the stratigraphy and description of the side slope subgrade it is unlikely that the materials will become unstable during the inert waste placement phases of the works; therefore, no further stability analysis of this component of the landfill is considered necessary.

Side Slope Lining System Screening

2.6 An artificially established side-lining system, comprising a minimum of either 0.5m thick with a permeability of $5 \times 10^{-8}$m/s or its equivalent a 1m liner with a permeability of $1 \times 10^{-7}$m/s is to be placed on the side slopes of the landfill. Given the expected gradient of the side slopes subgrade it is probable that the side slope lining system will be placed in sections; such that the side slope liner will not achieve drained conditions prior to the placement of inert waste.

2.7 Even though no groundwater outflows into the void have been identified during the mineral extraction works, for added stability safety individual 4.00m high lifts of liner will be designed to resist horizontal forces associated with the possibility of a piezometric surface.

2.8 Analysis of this component is considered necessary to investigate the short-and long-term stability of this element prior to the placement of the inert waste.

Waste Mass Screening

2.9 This component is considered to be an issue that will require a detailed geotechnical analysis in order to assess the stability of the waste mass.

Capping System Screening

2.10 Based on the finished proposed finished contours a maximum gradient of 1(v):30 (h) will be created which will remain stable under all foreseeable ground conditions. Therefore, no stability analysis of the restoration soils is considered necessary.

## Justification of Modelling Approach and Software

2.11 Two-dimensional limiting equilibrium stability analyses will be used in the assessment of the stability of the various components of the proposed Greetham Quarry. The method of analysis used in each particular case was determined from an examination of the form of failure being considered.

2.12 The stability analyses were carried out using the Slope/W computer programme.

2.13 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 Side Slopes Subgrade Analyses

Not a consideration at this site.

Parameters Selected for Side Slope Liner Analyses

2.14 The side slope liner is to be constructed using an appropriate fine-grained material. Typical values for clay materials have been used to define the characteristic geotechnical values of the side slope liner material (Table SRA4).

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

| Material | Unit Weigh | Total Stress | | Effective Stress | |
|---|---|---|---|---|---|
| | $\gamma$ (kN/m$^3$) | $c_{uk}$ (kN/m$^2$) | $\phi_{uk}$ (°) | $c'_k$ (kN/m$^2$) | $\phi'_k$ (°) |
| Side Liner | 19 | 50 | 0 | 2 | 25 |

Parameters Selected for Waste Analyses

2.15 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 SRA3. 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 materials 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.

2.16 Although it appears that the landfill will be above the groundwater level recorded in the Lincolnshire Limestone the construction of a geological barrier will prevent the ingress of groundwater into the inert waste mass such that the use of the buoyant unit weight is not required.

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

| Material | Bulk Unit Weight | Total Stress | | Effective Stress | |
|---|---|---|---|---|---|
| | $\gamma_k$ (kN/m$^3$) | $c_{uk}$ (kN/m$^2$) | $\phi_{uk}$ (°) | $c'_k$ (kN/m$^2$) | $\phi'_k$ (°) |
| Waste Mass | 17 | 50 | 0 | 5 | 25 |

## Selection of Appropriate Factors of Safety

2.17 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*φ) | | $\gamma_{\varphi'}$ | 1.00 |
| | | | Effective cohesion (*c'*) | | $\gamma_{c'}$ | 1.00 |
| | | | Undrained shear strength ($c_u$) | | $\gamma_{cu}$ | 1.00 |
| | | | Resistance R1 | | | |
| | | | Resistance | | $\gamma_{R;e}$ | 1.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 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 |
| | 2 | A2 + M2 + R1 | Materials M2 | | | |
| | | | Coefficient of shearing resistance (*tan*φ) | | $\gamma_{\varphi'}$ | 1.25 |
| | | | Effective cohesion (*c'*) | | $\gamma_{c'}$ | 1.25 |
| | | | Undrained shear strength ($c_u$) | | $\gamma_{cu}$ | 1.40 |
| | | | Resistance R1 | | | |
| | | | Resistance | | $\gamma_{R;e}$ | 1.00 |

2.18 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.

2.19 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

2.20 The side slopes of the void will be formed during the mineral extraction phase of the works and will be subject to appraisal under Regulation 33 of the Quarries Regulations. Therefore, no further stability assessment is required. Although their stratigraphy and groundwater conditions will be considered in the side slope liner analysis.

Side Slope Liner Analyses

2.21 A side slope liner will be placed against the side slope subgrade. Given the lithified nature of the side slope subgrade it is likely that side slopes will be stable at near vertical gradients. For the side slope liner stability assessment, it is assumed that the side slopes are at 80°.

2.22 Although no groundwater outflows have been reported during the mineral extraction works for completeness the volume required to resist sliding initiated by horizontal piezometric pressures has been determined for the stratigraphy and groundwater conditions present in the East Face of Phase B which represents the worst case.

2.23 The results of the sliding analyses are presented in Appendix 2 and indicate that a 4m high section of liner with a face angle of 1(V) to 2 (H) will have sufficient weight to resist the horizontal piezometric forces and achieve horizontal equilibrium.

2.24 The results of the side slope liner stability analyses are shown in Table SRA7 and the SlopeW worksheets presented in Appendix 3.

**Table SRA7: Side Slope Liner Stability – Summary of Results**

| Run | File Name | Shear Strength | | Factor of Safety | | Notes |
|---|---|---|---|---|---|---|
| | | c | $\phi$ | C1 | C2 | |
| Side Slope Gradient up to 80 ° | | | | | | |
| 01 | SLINER1 | 50 | 0 | 6.04 | | Total Stress |
| 02 | SLINER2 | 36 | 0 | | 5.94 | |
| 03 | SLINER3 | 2 | 25 | 0.48 | | long term exposure – Full effective stress conditions |
| 04 | SLINER4 | 1.6 | 20 | | 0.69 | |
| 05 | SLINER5 | 1.6 | 20 | 1.16 | 1.07 | Gradient slackened to 1(v) : 2 (h) |

<u>Waste Mass Analyses</u>

2.25 The post extraction void may be up to 10m deep. However, it is unlikely that a 10m high waste face would be created given the phasing and placement of the inert waste in layers. Therefore, the maximum slopes considered in this analysis will be 10m high and the waste during placement operations will be restricted to 1(v) : 3(h).

2.26 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.

2.27 Given the composition (inert materials), landfill gas pressures are unlikely to develop within the waste mass.

2.28 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.

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

2.30 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.

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

**Table SRA8: Waste Mass Stability – Summary of Results**

| Run | File Name | Waste Strength | Leachate Level | Factor of Safety | | Notes |
|---|---|---|---|---|---|---|
| | | | | C1 | C2 | |
| 11 | WMass1 | Total | Dry | 2.09 | | Total Stress |
| 12 | WMass2 | | | | 2.09 | |
| 13 | WMass3 | Effective | 1.00m | 1.58 | | Increasing leachate level measured from base of waste mass |
| 04 | WMass4 | | | | 1.20 | |
| 05 | WMass5 | | 4.00 | 1.29 | | |
| 06 | WMass6 | | | | 1.18 | |
| 07 | WMass7 | | 6.00 | 1.17 | | |
| 08 | WMass8 | | | | 1.01 | |
| 09 | WMass9 | | Not Present | 1.43 | | Cohesion = 0kN/m² |

## Assessment

Basal Subgrade

2.32 The basal subgrade is to comprise the in-situ Lincolnshire Limestone Formation which is considered competent and with no net increase in stress at basal subgrade level predicted, no settlement other than short term elastic recompression is expected. Therefore, the basal subgrade is considered appropriate without any significant re-engineering.

Basal Liner

2.33 A basal liner of locally sourced fine-grained material will be placed across the entire base of the void. The basal liner will comprise either 1.00m of clay with a hydraulic conductivity of $1.0 \times 10^{-7}$m/s or its equivalent of 0.5m of clay with a hydraulic conductivity of $5.0 \times 10^{-8}$m/s.

2.34 Current site conditions to the east of the site and groundwater elevations in the Lincolnshire Limestone Formation mean that uplift forces and hence basal heave is not a consideration at the site.

Side Slope Sub-Grade

2.35 The side slopes of the void will be formed as part of the mineral extraction works which is to be carried out by MGL. It is appropriate to assume that the extraction works will be subject to Geotechnical Appraisal under Regulation 33 of the Quarries Regulations and as part of that appraisal it will be demonstrated that the side slope subgrade is stable at the planned angle of excavation. The lithologies forming the side slope subgrade are unlikely to degrade over the time in which the void will be open. Given this and the design and appraisal under the mineral extraction phase of the works, the void must be considered as being stable at the angle at which the mineral extraction works are undertaken and the inert waste placement commences.

Side Slope Liner

2.36 Given the lithified nature of the side slope subgrade it is probable that the side slope liner will be placed in lifts to avoid long term exposure without support.

2.37 A 4m high lift of side slope liner has been analysed and is shown to be stable in the short term under total stress conditions with a minimum factor of safety of 5.94 being returned under Design Approach 1 Combination 2 factoring.

2.38 However, if left unsupported in the long-term such that fully drained effective stress conditions are achieved the liner becomes unstable. To achieve long term stability the side slope liner gradient needs to be slackened to 2(h) : 1(v) which then returns a factor of safety of 1.07 under the more onerous Combination 2 factoring.

2.39 Although no groundwater inflows from the Lincolnshire Limestone Formation have been reported during the mineral extraction works, an assessment of horizontal sliding of the liner indicates that under drained conditions a 4m high section of liner with a face gradient of 2(h) : 1(v) has sufficient weight to achieve horizontal equilibrium.

2.40 It can be concluded that placement of the side slope liner in lifts ahead of the waste placement will be stable in the short term. However, if the liner material is to be left unsupported for an extended period of time then it should be either buttressed by inert waste or placed with a minimum face gradient of 1(v) : 2(h).

Waste Mass

2.41 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.

2.42 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.

2.43 The waste slope has a factor of safety > 1 for all leachate levels up to 6.00m from the base of the waste body. A leachate level of 6.00m is considered extremely unlikely to occur under normal operating conditions and therefore represents a worst-case situation.

2.44 The waste slope has a factor of safety of 1.43 even if the value of the cohesion intercept of the waste reduces from 5kN/m$^2$ to 0kN/m$^2$.

2.45 It is concluded that a 1(v) : 3(h) waste slope will be stable for the range of leachate levels anticipated.

Capping System

2.46 Not a consideration at this site.

## 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, identify instability of the waste mass itself and instability of the side slope subgrade and lining system at the earliest possible juncture.

Basal Subgrade Monitoring

3.2 Prior to the placement of the waste it is recommended that the basal subgrade is carefully inspected to identify any areas where the Lincolnshire Limestone Formation has been exposed at the surface as a result of local faulting. If such area areas are identified it is recommended that localised placement of locally derived fine-grained material (the same as that used in the side liner construction) is placed to ensure the integrity of basal subgrade. If the basal subgrade is to be left exposed for any length of time a programme of routine monitoring should be undertaken to identify any soft spots that may develop as a result of exposure to inclement weather.

Side Slope Subgrade + Lining Monitoring

3.3 The side slopes should be visually monitored for instability during the 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.

Basal Lining System Monitoring

3.4 The basal liner is to comprise locally sourced fine-grained material which will be placed as either 1.00m of clay with a hydraulic conductivity of $1.0 \times 10^{-7}$m/s or its equivalent of 0.5m of clay with a hydraulic conductivity of $5.0 \times 10^{-8}$m/s. The basal lining will be across the whole of the site but will obviously not be constructed as a single entity and will be built in stages

Waste Mass Monitoring

3.5 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

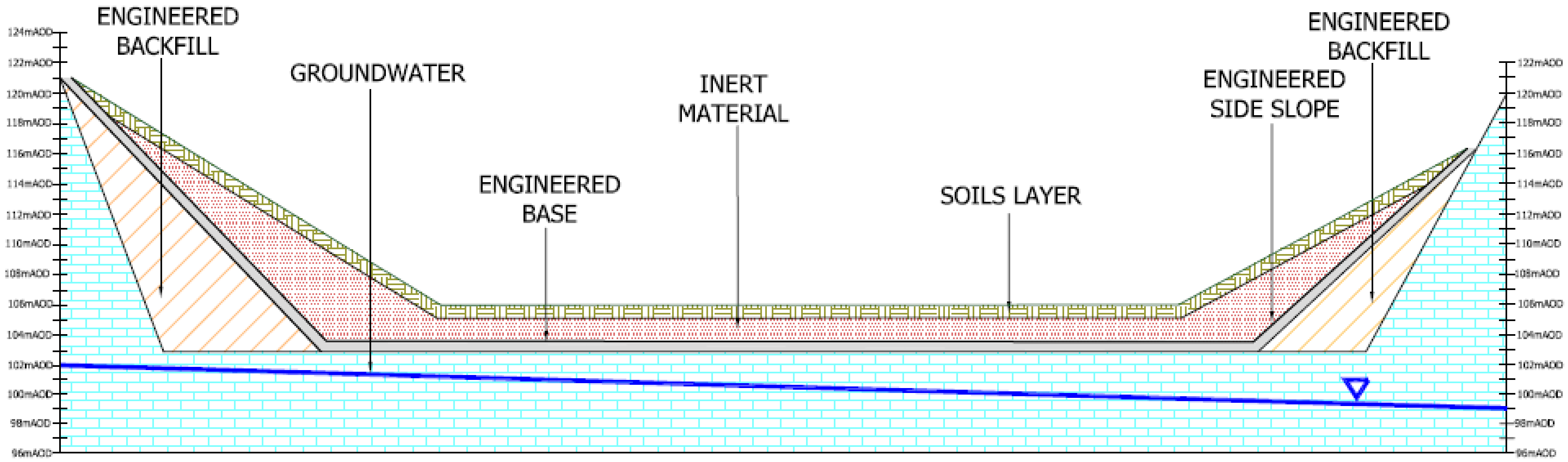
3.6 The condition of the surface of all restored areas will be monitored on a regular basis as part of the site inspection regimen.

3.7 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. In the event that any symptom of incipient failure is detected the Environment Agency will be informed and a site action plan for remediation agreed.

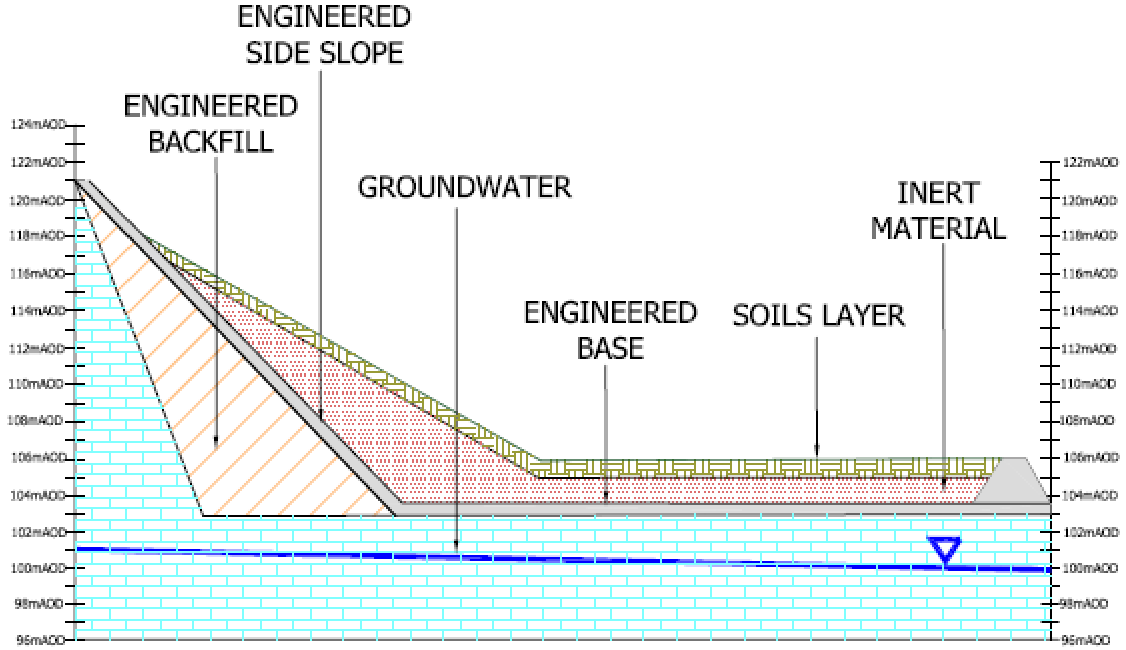
3.8 The Surface of the restored areas will be monitored by land survey techniques on a regular basis. These checks will be on a biannual basis for the first two years and then on an annual basis to the fifth year after restoration, when the periodicity reviewed with the Environment Agency.

# Appendix 1

# Conceptual Site Model Cross Sections



ENGINEERED BACKFILL
GROUNDWATER
INERT MATERIAL
ENGINEERED BASE
SOILS LAYER
ENGINEERED SIDE SLOPE
ENGINEERED BACKFILL
124mAOD
122mAOD
120mAOD
118mAOD
116mAOD
114mAOD
112mAOD
110mAOD
108mAOD
106mAOD
104mAOD
102mAOD
100mAOD
98mAOD
96mAOD

ENGINEERED SIDE SLOPE
ENGINEERED BACKFILL
GROUNDWATER
INERT MATERIAL
ENGINEERED BASE
SOILS LAYER
124mAOD
122mAOD
120mAOD
118mAOD
116mAOD
114mAOD
112mAOD
110mAOD
108mAOD
106mAOD
104mAOD
102mAOD
100mAOD
98mAOD
96mAOD

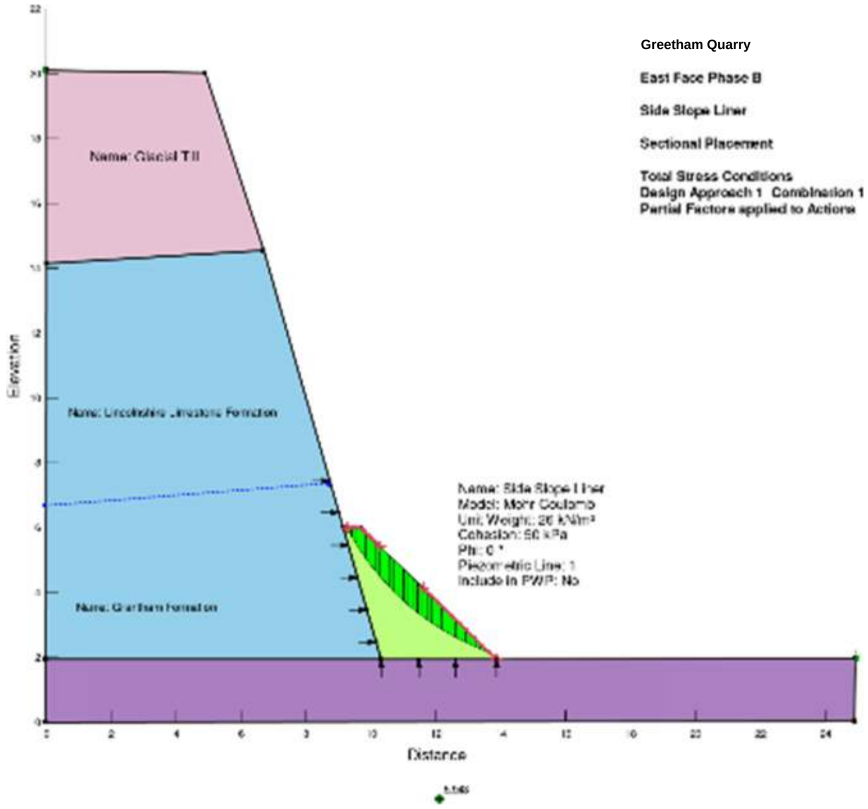
# Appendix 2

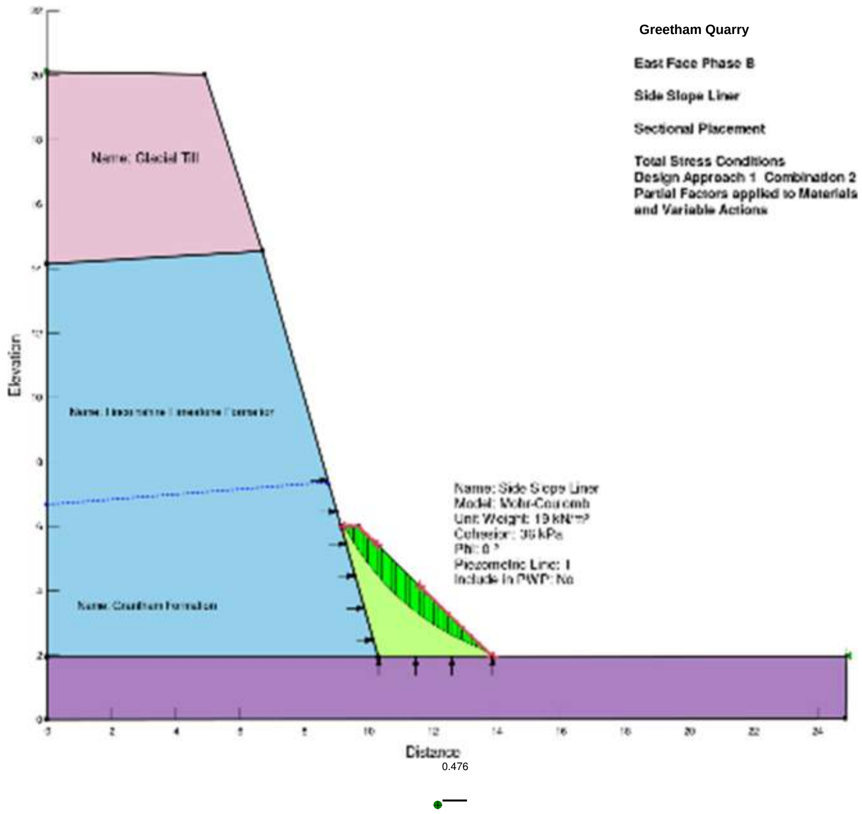
# Liner Sliding Calculations

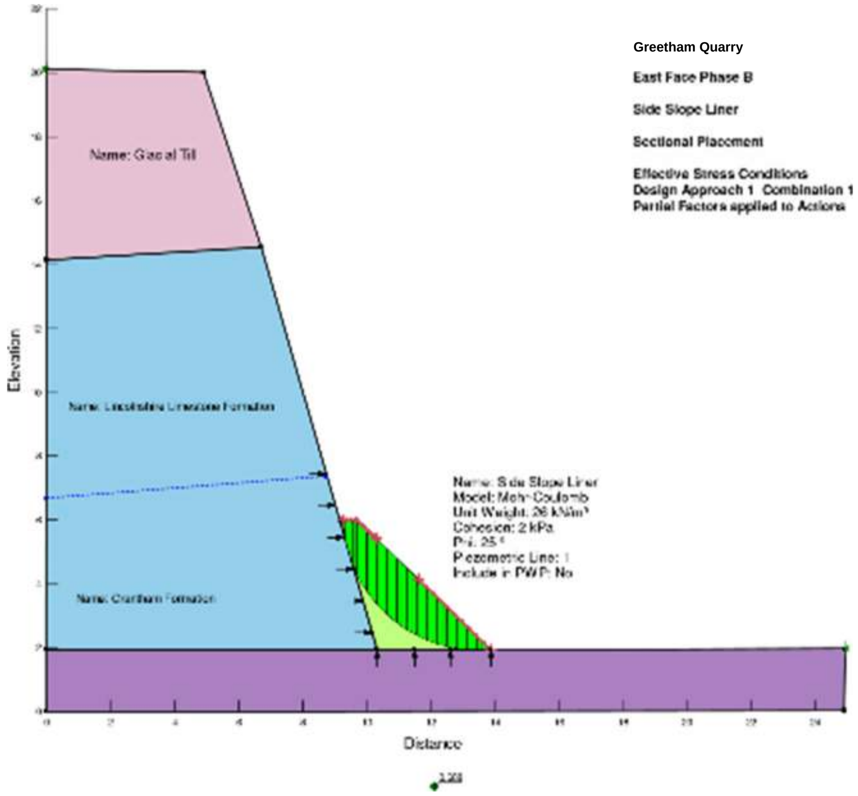
# Appendix 3

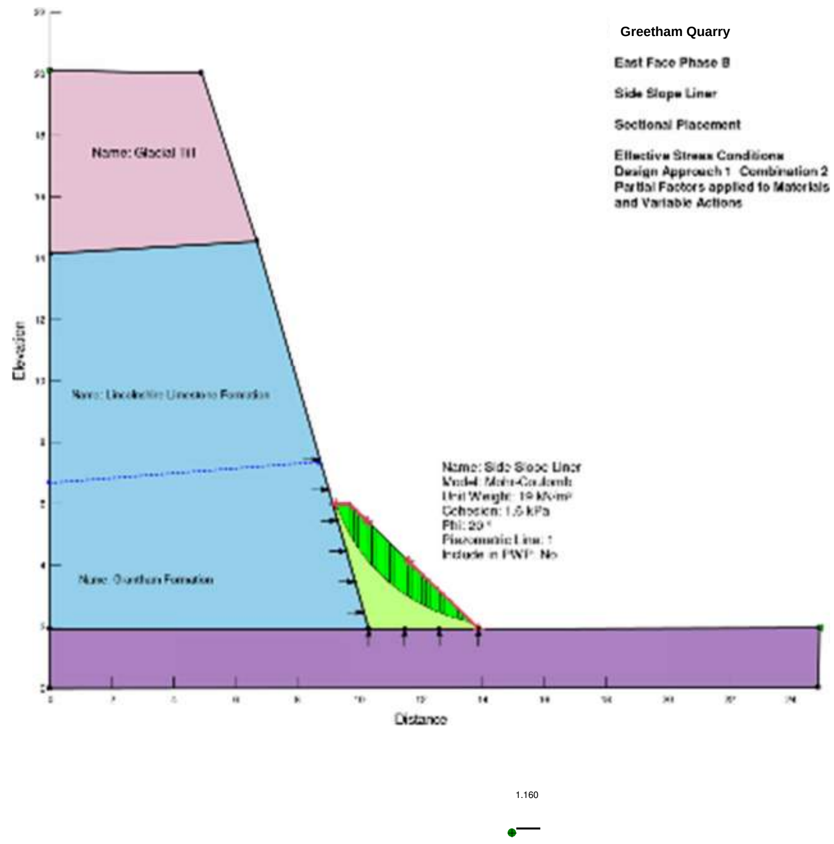
# SlopeW Worksheets – Side Slope Liner

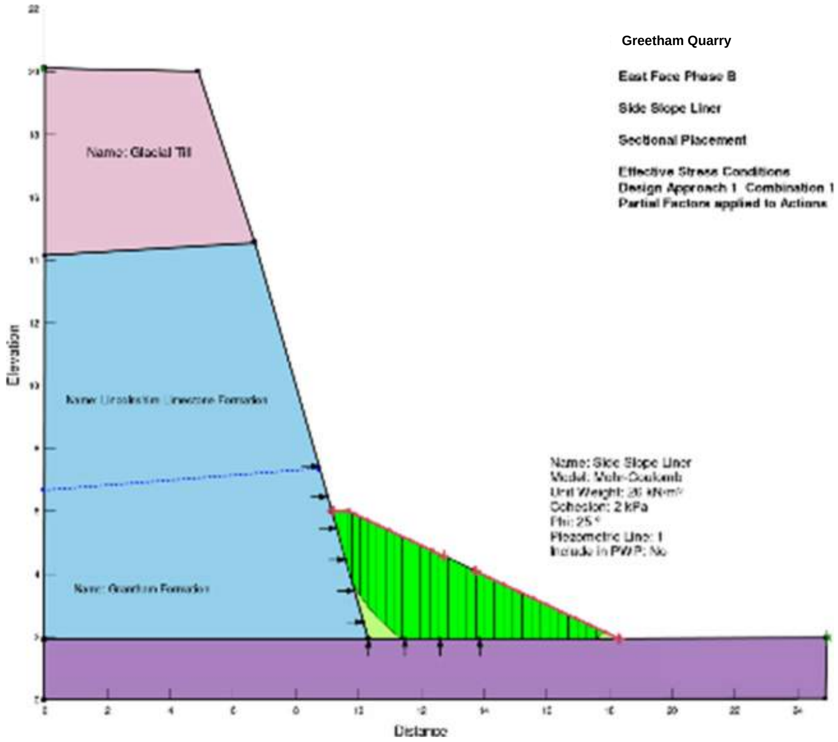
6.032


Greetham Quarry
East Face Phase B
Side Slope Liner
Sectional Placement
Total Stress Conditions
Design Approach 1 Combination 1
Partial Factors applied to Actions
Name: Glacial Till
Name: Lincolnshire Limestone Formation
Name: Grantham Formation
Name: Side Slope Liner
Model: Mohr Coulomb
Unit Weight: 20 kN/m³
Cohesion: 50 kPa
Phi: 0 °
Piezometric Line: 1
Include in PWP: No
Elevation
Distance

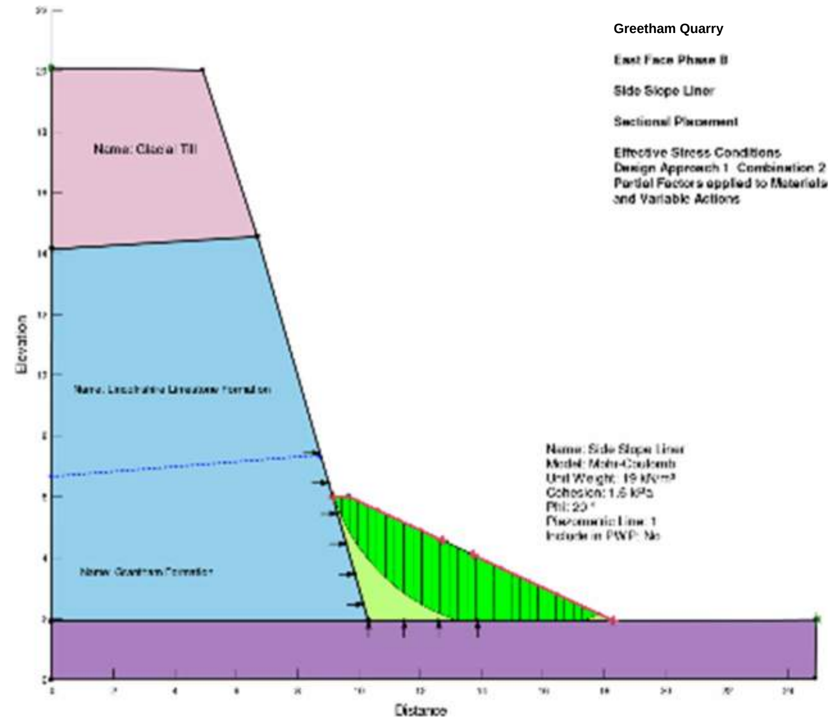

Greetham Quarry
East Face Phase B
Side Slope Liner
Sectional Placement
Total Stress Conditions
Design Approach 1 Combination 2
Partial Factors applied to Materials
and Variable Actions
Name: Glacial Till
Name: Side Slope Liner
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion: 36 kPa
Phi: 0 °
Piezometric Line: 1
Include in PWP: No
Elevation
Distance
0.476


Greetham Quarry
East Face Phase B
Side Slope Liner
Sectional Placement
Effective Stress Conditions
Design Approach 1 Combination 1
Partial Factors applied to Actions
Name: Glacial Till
Name: Lincolnshire Limestone Formation
Name: Grantham Formation
Name: Side Slope Liner
Model: Mohr-Coulomb
Unit Weight: 26 kN/m³
Cohesion: 2 kPa
Phi: 25 °
Piezometric Line: 1
Include in PWP: No
Elevation
Distance


Greetham Quarry
East Face Phase B
Side Slope Liner
Sectional Placement
Effective Stress Conditions
Design Approach 1 Combination 2
Partial Factors applied to Materials and Variable Actions
Name: Glacial Till
Name: Lincolnshire Limestone Formation
Name: Grantham Formation
Name: Side Slope Liner
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion: 1.5 kPa
Phi: 20 °
Piezometric Line: 1
Include in PWP: No
Elevation
Distance
1.160

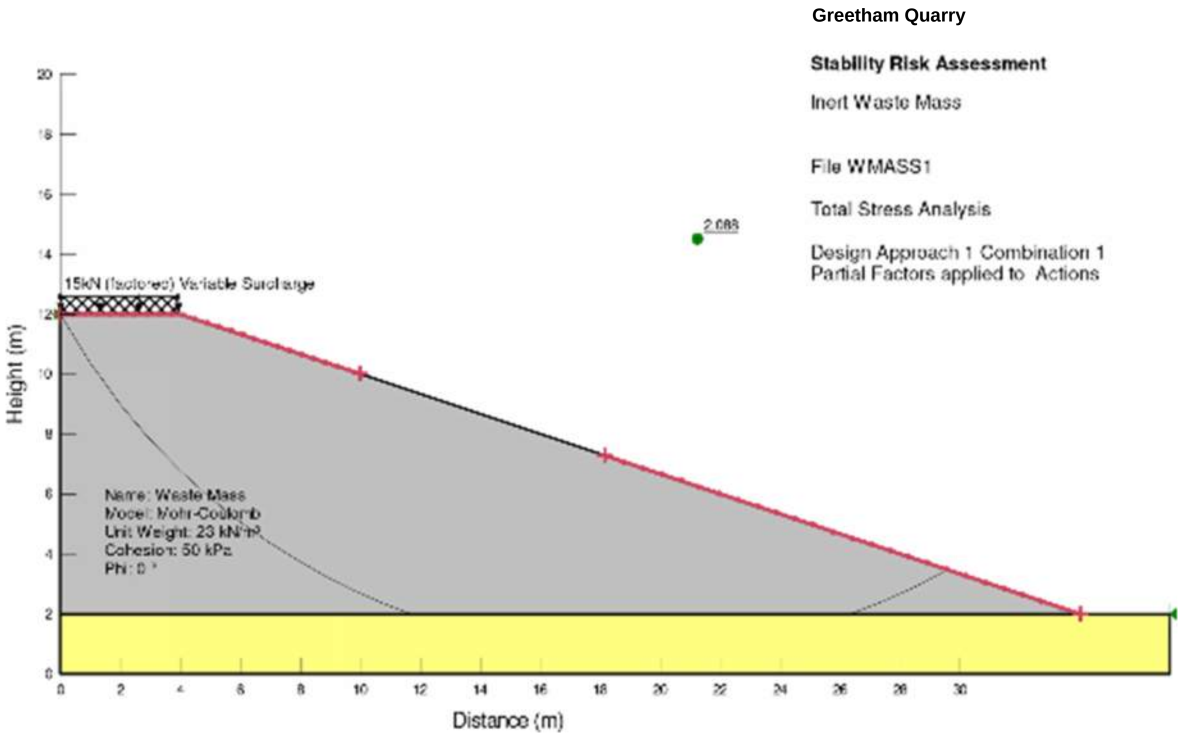

Greetham Quarry
East Face Phase B
Side Slope Liner
Sectional Placement
Effective Stress Conditions
Design Approach 1 Combination 1
Partial Factors applied to Actions
Name: Glacial Till
Name: Lincolnshire Limestone Formation
Name: Grantham Formation
Name: Side Slope Liner
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 2 kPa
Phi: 25 °
Piezometric Line: 1
Include in PWP: No
Elevation
Distance

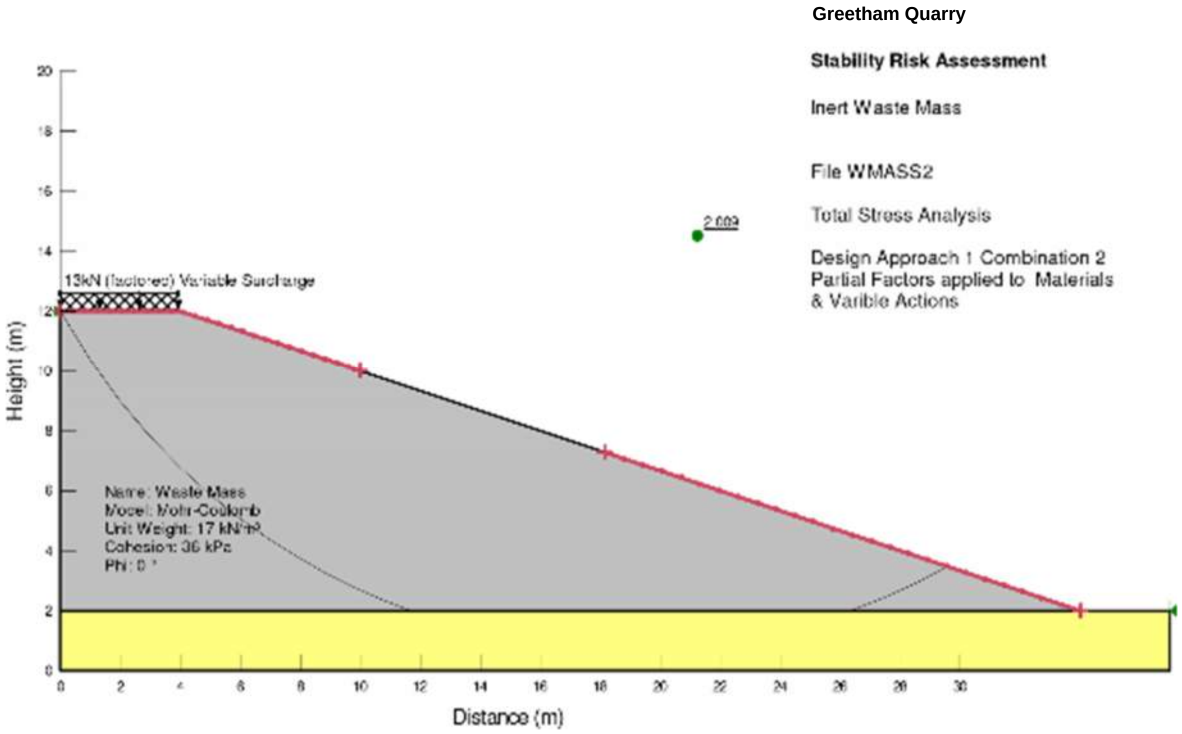
1.073

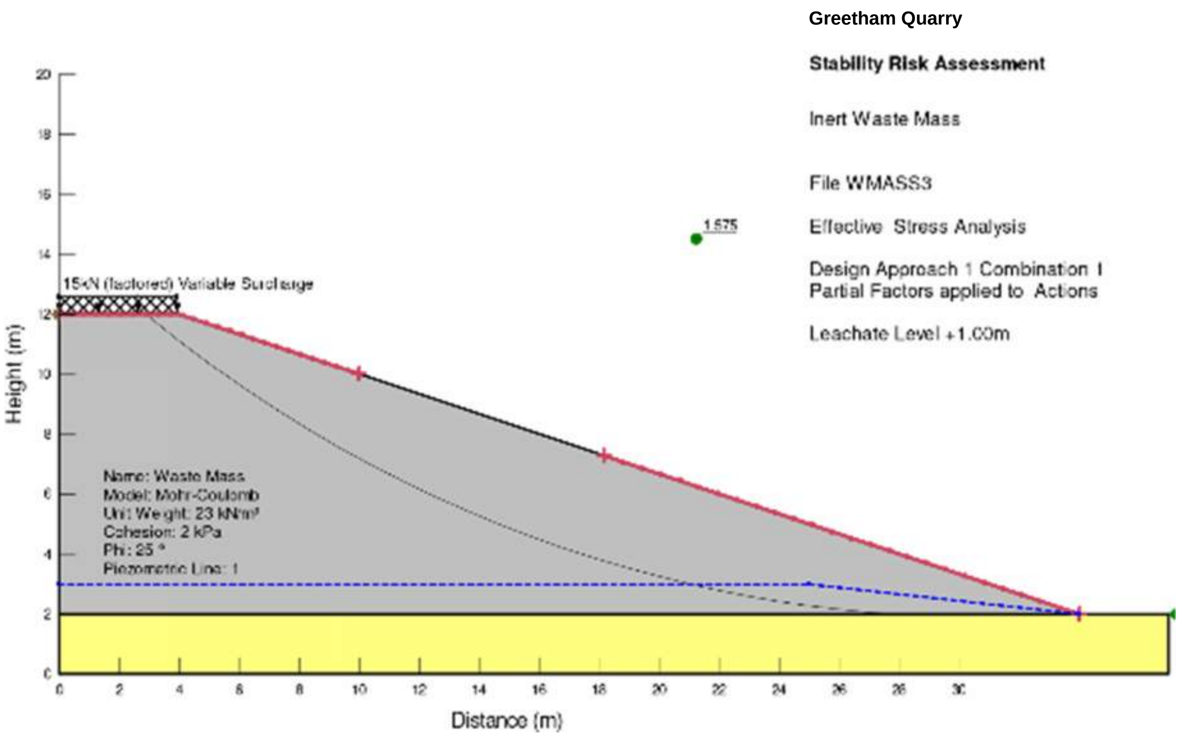

Greetham Quarry
East Face Phase B
Side Slope Liner
Sectional Placement
Effective Stress Conditions
Design Approach 1 Combination 2
Partial Factors applied to Materials and Variable Actions
Name: Glacial Till
Name: Lincolnshire Limestone Formation
Name: Grantham Formation
Name: Side Slope Liner
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion: 1.6 kPa
Phi: 20 °
Piezometric Line: 1
Include in PWP: No
Elevation
Distance

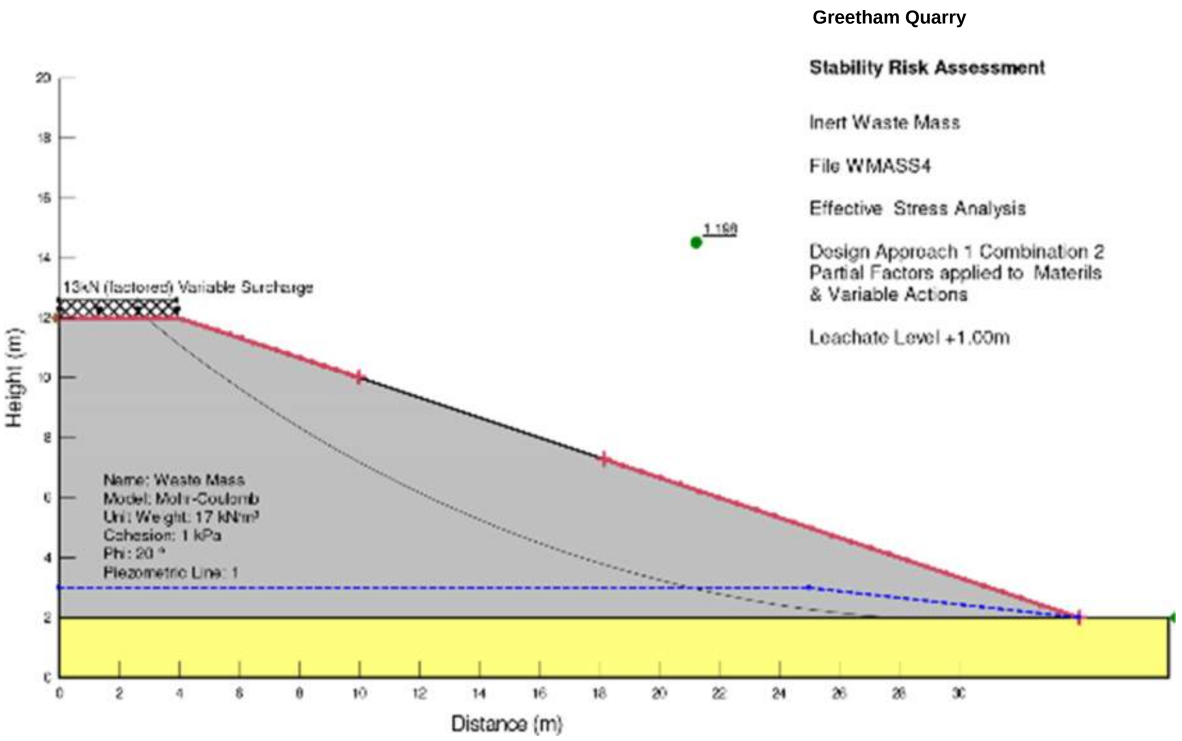
# Appendix 4

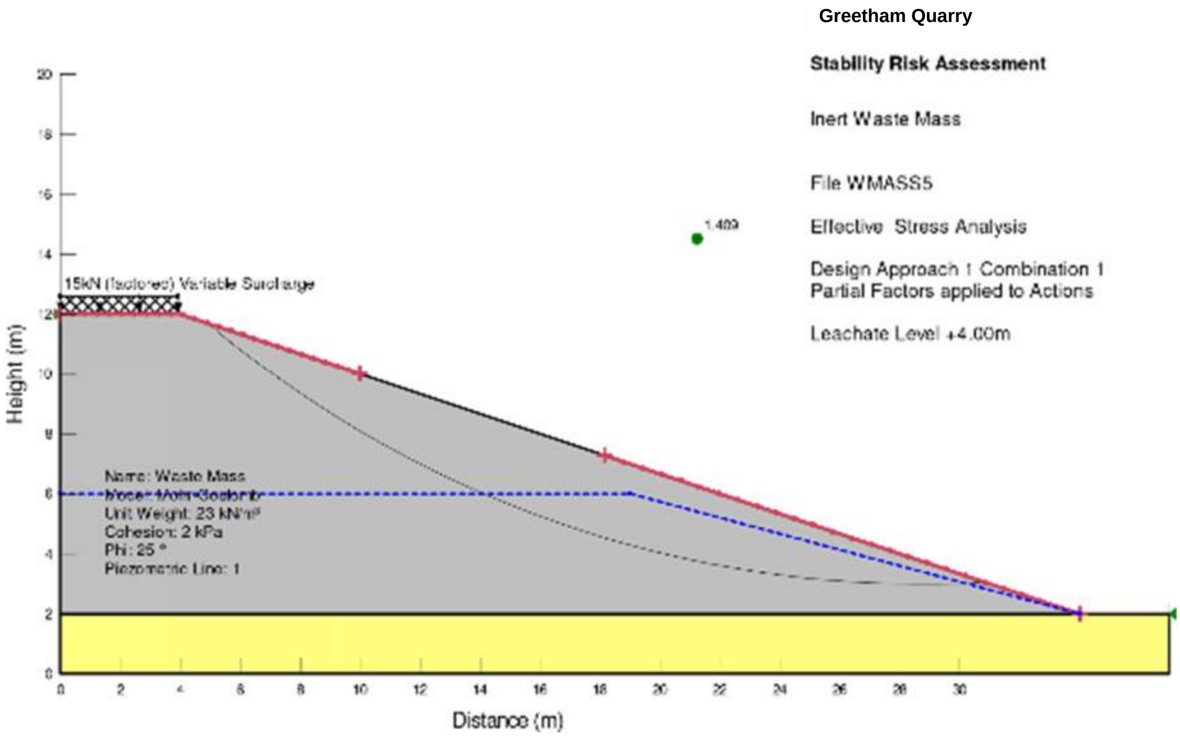
# Slope W Worksheets – Inert Waste Mass

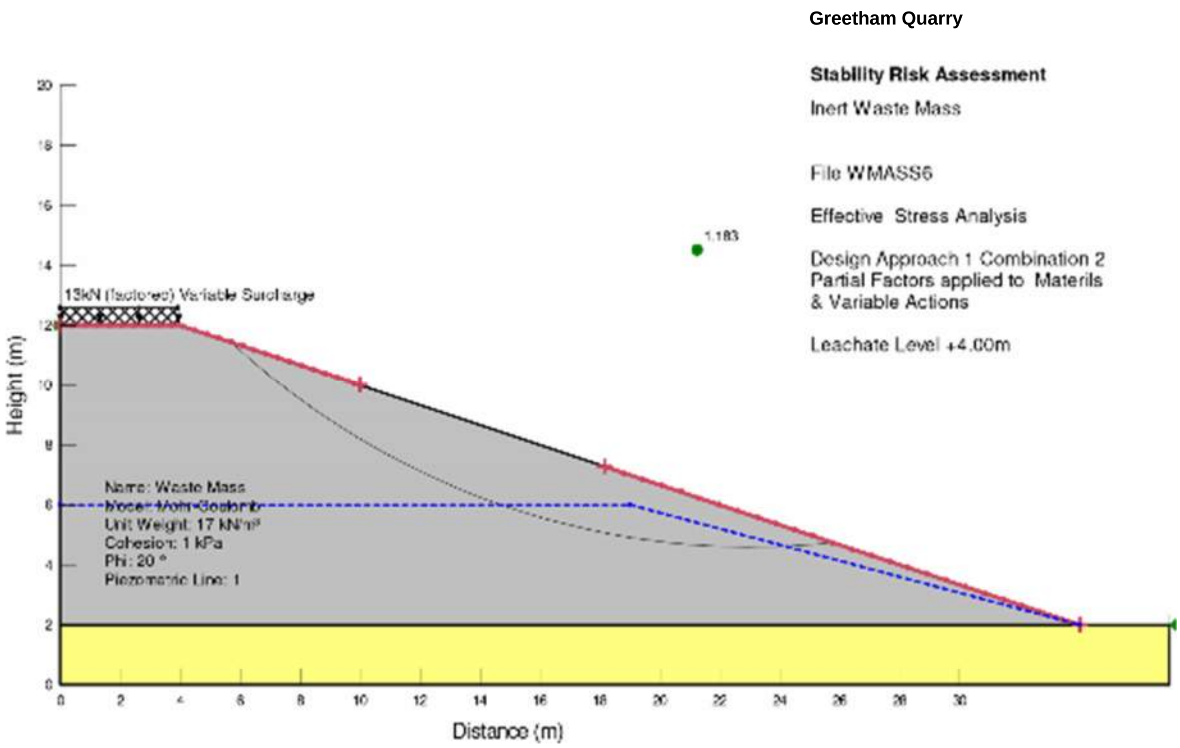

Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS1
Total Stress Analysis
Design Approach 1 Combination 1
Partial Factors applied to Actions
15kN (factored) Variable Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 23 kN/m³
Cohesion: 50 kPa
Phi: 0 °
Height (m)
Distance (m)

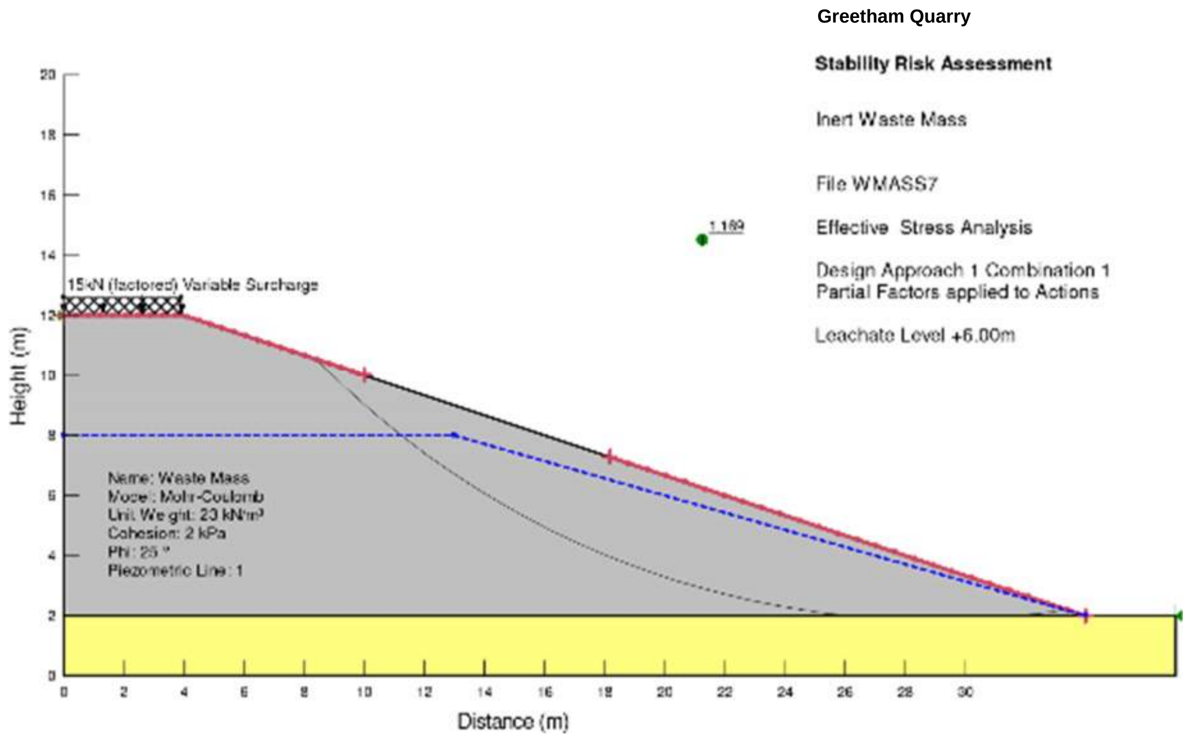

Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS2
Total Stress Analysis
Design Approach 1 Combination 2
Partial Factors applied to Materials
& Varible Actions
13kN (factored) Variable Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 36 kPa
Phi: 0 °
Height (m)
Distance (m)

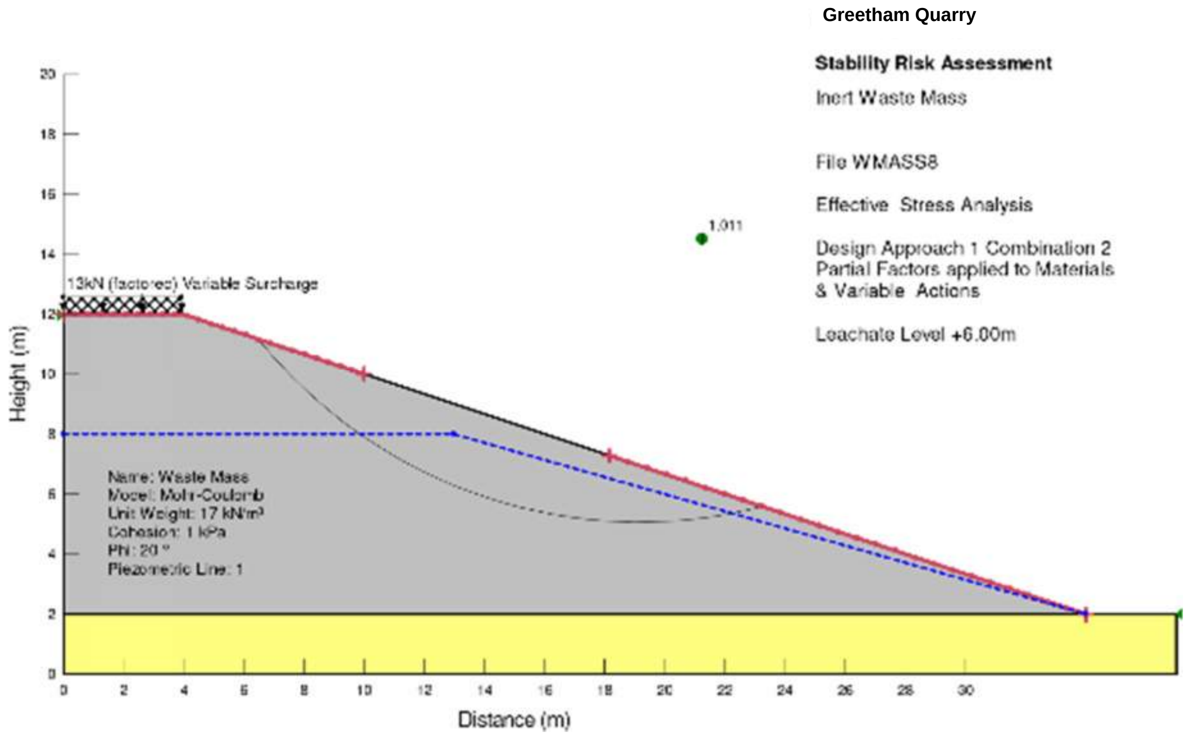

Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS3
Effective Stress Analysis
Design Approach 1 Combination I
Partial Factors applied to Actions
Leachate Level +1.00m
1.575
15kN (factored) Variable Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 23 kN/m³
Cohesion: 2 kPa
Phi: 25 °
Piezometric Line: 1
Height (m)
Distance (m)

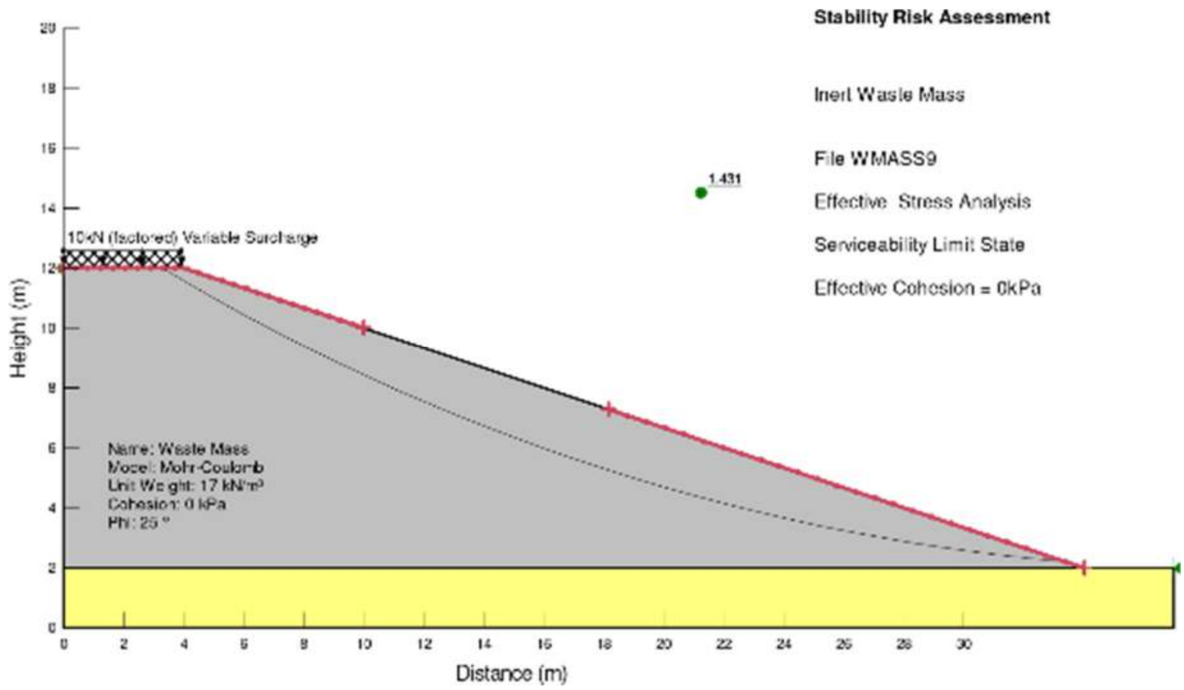

Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS4
Effective Stress Analysis
Design Approach 1 Combination 2
Partial Factors applied to Materils
& Variable Actions
Leachate Level +1.00m
1.198
13kN (factored) Variable Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 1 kPa
Phi: 20 °
Piezometric Line: 1
Height (m)
Distance (m)


Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS5
Effective Stress Analysis
Design Approach 1 Combination 1
Partial Factors applied to Actions
Leachate Level +4.00m
1.409
15kN (factored) Variable Surcharge
Name: Waste Mass
Unit Weight: 23 kN/m³
Cohesion: 2 kPa
Phi: 25 °
Piezometric Line: 1
Height (m)
Distance (m)


Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS6
Effective Stress Analysis
Design Approach 1 Combination 2
Partial Factors applied to Materils
& Variable Actions
Leachate Level +4.00m
1.183
13kN (factored) Variable Surcharge
Name: Waste Mass
Unit Weight: 17 kN/m³
Cohesion: 1 kPa
Phi: 20 °
Piezometric Line: 1
Height (m)
Distance (m)


Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS7
Effective Stress Analysis
Design Approach 1 Combination 1
Partial Factors applied to Actions
Leachate Level +6.00m
1.189
15kN (factored) Variable Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 23 kN/m³
Cohesion: 2 kPa
Phi: 25 °
Piezometric Line: 1
Height (m)
Distance (m)


Greetham Quarry
Stability Risk Assessment
Inert Waste Mass
File WMASS8
Effective Stress Analysis
Design Approach 1 Combination 2
Partial Factors applied to Materials
& Variable Actions
Leachate Level +6.00m
1.011
13kN (factored) Variable Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 1 kPa
Phi: 20 °
Piezometric Line: 1
Height (m)
Distance (m)


Stability Risk Assessment
Inert Waste Mass
File WMASS9
Effective Stress Analysis
Serviceability Limit State
Effective Cohesion = 0kPa
1.431
10kN (factored) Variable Surcharge
Name: Waste Mass
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 0 kPa
Phi: 25 °
Height (m)
Distance (m)