REPORT

Park Grounds Landfill

Stability Risk Assessment

Submitted to:

Crapper & Sons Landfill Ltd
Park Grounds
Brinkworth Road
Royal Wootton Bassett
Wiltshire
SN4 8DW

Submitted by:

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Distribution List

Crapper & Sons Landfill Ltd: 1 copy (PDF)

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APPENDICES

1.0 INTRODUCTION

1.1 Report Context

Crapper & Sons Landfill Ltd (Crapper), the owner and operator of the Park Grounds Landfill Site (the 'Site), has requested Golder Associates (UK) Ltd (Golder) to produce a Stability Risk Assessment as part of the application to vary the existing Environmental Permit for the Site. The permit variation application has been managed by Sol Environment Ltd (Sol Environment) on behalf of Capper.

The Stability Risk Assessment has been prepared in accordance with the Environment Agency R&D Technical Report P1-385/TR2 (Reference 1). This document considers the stability of the proposed variation within the area of proposed extension as well as its impact to the existing landfilling areas.

The assistance of Crapper and Sol Environment in the provision of data for this work is gratefully acknowledged. Golder has not independently verified any of the information supplied.

1.2 Outline of Installation

1.2.1 Site Location

Park Grounds Landfill is centred at National Grid Reference (NGR) SU 052 839 and is located approximately 2 km northwest of Royal Wootton Bassett, Wiltshire. The M4 motorway forms the southern boundary of the site and the B4042 Brinkworth Road passes roughly east-west to the north of the site. Access is via a metalled track off the B4042. The entrance is signed and has lockable wooden gates.

1.2.2 Site Classification

The site is classified as a landfill for the disposal of non-hazardous and inert wastes.

1.2.3 Site Description

The landfill is bounded to the south by the M4 Motorway and a railway to the southwest. Former farm buildings, materials recovery facility and composting area owned and operated by Crapper & Sons are located north of the central landfill area. Land to the north, west and east of the site comprises arable and low quality grazing, see Drawing 2437/ESSD/D2.

The site comprises an active landfill, Materials Recovery Facility (MRF), recycling, composting facility and a closed landfill. The existing permit covers the closed landfill in the far east and northeast and the current landfill in the centre and west of the site (Drawing 2437/ESSD/D4). The closed landfill area was largely inert with only the last 3, northernmost, cells (cells A-C) comprising non-hazardous waste. The closed landfill comprised a land raising operation, infilling a low valley and raising elevations to form a small local hilltop. It was restored to a gently domed profile with a maximum election of 98 metres Above Ordnance Datum (mAOD).

Land to the northeast of the current landfill is used for the recycling and composting operations. A new building is being constructed to house these processes together with a new gasification plant which are all regulated by a separate permit. The site offices and meeting rooms occupy the former farmhouse.

The current landfill area comprises 13 cells (Cells 1 to 10, 1A, 1B and an asbestos cell). The site is filled with non-hazardous waste commencing in the southwest and following a roughly clockwise direction. A small asbestos cell is located towards its centre. Landfilling is currently being undertaken in Cell 9 and Cell 10 has been engineered to accept waste. A further five cells occupy the recently granted western extension area; Cells 11 to 15.

1.3 Geology

The site is underlain by dark blue-grey, over-consolidated Oxford Clay, which dips gently to the east. The log of a borehole near Purton (Purton House), 5.5 km northeast of the site, indicates a thickness of the Oxford Clay in excess of 88 m. The Oxford Clay contains 'clay stone' horizons in places. Of the nineteen closest boreholes to the site, claystones were only identified in two. However, they have been identified in places at the site (noted in the construction quality assurance (CQA) report for Cell 9 as random and up to 75 mm thick). Based on the nearby borehole data, it is assumed that these claystones are not laterally continuous in the vicinity of the site. The logs of BGS boreholes are provided on Appendix 2437/ESSD/A2.

The overlying Corallian strata (now the Stamford Formation), a detrital limestone, outcrop at Royal Wootton Bassett, 5 km east of the site. It is therefore considered likely that almost the full thickness of Oxford Clay is present beneath the site. Only the feather edge of the Corallian is present in a north-south exposure, the remainder being capped by the overlying Kimmeridge Clay further to the east.

The Kellaways Beds underlie the Oxford Clay and are in turn underlain by the Cornbrash which is the uppermost formation of the Great Oolite Series. The Kellaways Beds comprise grey mudstone, which is commonly silty or sandy with siltstone or sandstone beds, particularly in the upper horizons. It is in the order of 10 to 20 m thick. The Cornbrash comprises a bluish-grey or yellow-brown, fine to medium-grained bioclastic limestone. It is up to 10 m thick in the region (based on the BGS generalised section on 1:50,000 Sheet 252, Swindon).

Shallow alluvial deposits occur in the vicinity of Thunder Brook south of the railway and 140 m south of the proposed permit boundary.

1.4 Historical Development

Landfilling commenced in 1986 south of the existing former farm buildings and proceeded eastwards using inert wastes. After 1988 the licence was modified to allow the northernmost part of the landfill (Cells A to C) to be filled with non-hazardous waste. Landfilling in this area ceased in 1989.

The landfilling of the current area commenced operation in 1990. Before this the land comprised low quality grazing land.

Landfilling commenced in the southwest, in Cell 1 (Drawing 2437/ESSD/D4). Cells 1, 1A and 1B do not have a constructed, engineered clay layer; however the exposed clay surface forming the cell base and sides was compacted using heavy mobile plant. Clay liners (300 mm thick) were engineered in the base and sides of Cells 2 and 3. Landfill Directive compliant clay lining has been applied from Cell 4 onwards, comprising a minimum 1 m thick (more frequently 1.5 m) re-worked clay mineral liner. On completion of filling each cell, a 1 m thick clay cap was constructed.

In order to obtain material for the sidewalls, base and cap, clay is extracted from the base of each cell, resulting in the base being between 1 and 2 m below original ground levels in Cells 1 to 6. From Cell 7 onwards the depth of clay extraction for re-use on-site increased to between 6 to 7 m to allow for a cut basal elevation of approximately 81 to 82 m AOD and a formation level for each cell of approximately 82 to 83 m AOD.

1.5 Proposed Development

The proposed permit variation relates to the western extension area recently granted planning permission (Cells 11 to 15). The waste types, landfill engineering, leachate management etc., will continue as per current practices. The agreed final contours and after care scheme will also be revised to include the western extension area.

It is proposed to increase the waste input rates as below:

- Non-hazardous: 60,000 tonnes per annum;
- Inert: 20,000tonnes per annum.

Landfilling is currently on-going in Cell 9 with Cell 10 engineered ready to receive waste.

The proposed layout/phasing of the site is provided on Drawing 2437/ESSD/D4.

The agreed post-settlement contours are shown on Drawing 2437/ESSD/D5. It is expected that little settlement will occur across the landfill due to the waste types accepted.

A summary of the engineering for the site is shown on Drawing 2437/ESSD/D6.

1.6 Conceptual Stability Site Model

1.6.1 Basal Sub-Grade Model

The proposed extension cells at Park Grounds Landfill Site will be developed under the principle of an engineered landfill. The base of the extension cells will be lined with minimum 1.0 m thick low permeability clay liner. It is understood that no distinct groundwater body exists within the Oxford Clay and no aquifers or water-bearing strata occur within the immediate vicinity of the site. Therefore, there is no basal heave assessment required.

1.6.2 Side Slopes Sub-Grade Model

It is envisaged that a side slope will be formed along the edge of the extension cells by excavating into the ground for approximately 3 m along the edge and placing engineered fill above the ground. The side slope will be constructed to 1 vertical (v):4 horizontal (h) slopes as the sub-grade of the side slope lining system.

1.6.3 Basal Lining System Model

The conceptual basal liner design system will comprise minimum 1.0 m of clay with a hydraulic conductivity equal to or less than 1 x 10^{-9} m/s. The intention is to source the clay from suitable on-site materials.

1.6.4 Side Slopes Lining System Model

The basal geological barrier would be extended up the shallow side walls. The shallow side walls will be profiled to provide an engineered 1v:4h slope.

1.6.5 Waste Mass Model

The landfill classification of Park Grounds Landfill will be Non-Hazardous and Inert. Only non-hazardous and inert solid wastes will be deposited within the site. The maximum gradient of temporary waste slope has been proposed as 1v:2h (26.6º) in between different cells.

The leachate compliance levels in all cells will comprise a leachate head above the base of no more than 1 m as measured at the remote leachate monitoring wells. It is proposed that leachate will be extracted from the phases to maintain leachate heads within each phase below the compliance level of 1 m.

1.6.6 Capping System Model

Capping system will be constructed using Oxford Clay engineered to provide a minimum 1 m thick layer with a maximum permeability of 1 x 10^{-9} m/s.

The low permeability engineered capping layer, will be protected through the placement of 1.0 m thick of restoration soils (750 mm subsoil and 250 mm topsoil). Once the restoration soils have been placed they will be seeded with a grass mix and returned to agriculture.

1.6.7 Leachate Extraction System Model

The base of each of the non-hazardous cells is graded to provide a fall to the leachate collection sump. In Cells 5 and 6, the leachate drainage is supplemented with a herringbone drainage system comprising high density polyethylene (HDPE) pipe with a coarse gravel surround.

From Cell 7 onwards a drainage layer of baled tyres is placed in the base of each cell together with herringbone HDPE pipes as above. The tyre bales are placed on top of a geotextile layer to distribute the weight of the baled tyre and prevent damage of the mineral clay liner. HDPE 180 mm diameter slotted drainage pipe is placed between the baled tyres to direct leachate to the leachate sump at the lowest point on the base of the cell. The pipework is then surrounded with aggregate and this is also used to infill any gaps between the baled tyres. This is understood to be arrangement proposed for the new cells.

2.0 STABILITY RISK ASSESSMENT

2.1 Risk Screening

2.1.1 Basal Sub-Grade and Lining System Screening

The site investigation data indicates there are no cavities beneath the site and any compressible material will be removed prior to construction. The foundation of Oxford Clay is considered to be stable and not subject to any significant settlement, either total or differential, that would lead to unacceptable strains in the lining system.

Since a distinct groundwater body does not exist within the Oxford Clay and no aquifers or water-bearing strata occur within the immediate vicinity of the site, basal heave is therefore not considered to be an issue at the site. Therefore no further assessment is required for the basal sub-grade and lining system.

2.1.2 Side Slopes Sub-Grade and Lining System Screening

The stability of the 1v:4h side slope sub-grade prior to placement of the lining system requires assessment.

2.1.3 Side Slopes Lining System Screening

The side slope lining systems are extensions of the basal lining system, extended up the face of the engineered slopes. The stability of the 1v:4h side slope clay liner requires assessment.

2.1.4 Waste Mass Screening

Waste will be filled in phases; temporary waste slopes will therefore be present. Assessment is required for the temporary waste slopes. It is proposed that the maximum gradient of the temporary waste slope is 1v:2h. The highest temporary waste slope is expected to be approximately 15.0 m high.

2.1.5 Capping System Screening

The low permeability clay capping system requires assessment for stability of the restoration soils.

2.2 Selection of Appropriate Factors of Safety

2.2.1 Factor of Safety for Side Slopes Sub-Grade

A minimum factor of safety of 1.3 against failure in the engineered fill side slope sub-grade will be considered acceptable providing reasonably conservative material strength parameters have been used.

2.2.2 Factor of Safety for Side Slope Lining System

A minimum factor of safety of 1.3 will be considered acceptable for overall stability of the lining system providing reasonably conservative strength parameters are used.

2.2.3 Factor of Safety for Waste Mass

A minimum factor of safety of 1.3 against failure in the waste mass will be considered acceptable providing reasonably conservative material strength parameters have been used.

2.2.4 Factor of Safety for Capping System

A minimum factor of safety of 1.3 will be considered acceptable for overall stability providing reasonably conservative strength parameters have been used.

2.3 Justification for Modelling Approach and Software

Methods of analysis are those described in the *de facto* Environment Agency Guidelines *'Stability of Landfill Lining Systems'* (Environment Agency, 2003).

2.3.1 Stability of Side Slope Sub-Grade

The analysis of the engineered fill side slope sub-grade has been carried out for circular failure surfaces (Morgenstern-Price method) using the Slope/W computer code. Ground water levels in the sub-grade have been modelled using a pore water pressure ratio, i.e. an r_u value.

2.3.2 Stability and Integrity of Side Slope Liner

The analysis of the engineered clay side slope lining has been carried out for circular failure surfaces (Morgenstern-Price method) using the Slope/W computer code. The clay lining system has been assessed using effective stress conditions. Ground water levels in the sub-grade have been modelled using a pore water pressure ratio, i.e. an r_u value.

2.3.3 Stability of Temporary Waste Slopes

The analysis of the existing temporary waste slopes with a gradient of 1v:2h has been carried out for a range of failures using the Slope/W computer code. Leachate levels of 1m and 2 m have been modelled using a peizometric line. The effects of rainfall infiltration and leachate recirculation have also been modelled using a pore water pressure ratio, i.e. an r_u value.

2.3.4 Stability of Capping System

The stability and the capping system has been carried out using the steepest and highest section taken through the proposed post-restoration pre-settlement contours. The stability of the restoration soils has been assessed using the finite slope approach to assess the stability of the restoration soils. This method has assessed the stability of the capping system model with dry, partially saturated and fully saturated restoration soils.

2.3.5 Stability of Leachate Extraction and Monitoring System

Calculations have been carried out to assess the stability of the leachate extraction system for total and effective stress conditions on the basal liner and differential settlement. In addition, calculations have been carried out to assess the deflection of the leachate pipe work.

2.4 Justification of Geotechnical Parameters Selected for Analyses

This section describes the parameters used in the Stability Risk Assessment. Parameter values have been selected based on a combination of the available site data, Golder's in-house experience and the technical literature. At all stages in the analysis conservative parameters have been selected, and where practicable, ultimate limit state parameters checked to ensure that failure is not likely with extreme conditions. The geotechnical parameters should be verified by site-specific tests during the construction stage.

2.4.1 Parameters Selected for Side Slope Sub-Grade Analyses

It is understood that excavated Oxford Clay will be used as the sub-grade engineered fill material to create 1v:4h side slopes. The material parameters used in the Slope/W analyses of the side slopes sub-grade are presented in Table 501/1.

Table 501/1: Material Parameters

Material	Unit weight (kN/m^3)	Cohesion (kPa)	Friction angle (°)
Engineered Fill	20	1	22
In Situ Oxford Clay	20	2	22

2.4.2 Parameters Selected for Side Slope Liner Analyses

The material parameters for clay liner used in the Slope/W for the side slope are presented in Table 501/2.

Table 501/2: Summary of Parameters Selected for Side Slope Liner Analyses

Material	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (°)
Clay Liner – Undrained	20	50	0
Clay Liner – Drained	20	1	22
Engineered Fill	20	1	22
In Situ Oxford Clay	20	2	22

2.4.3 Parameters Selected for Waste Analyses

The material parameters used in the Slope/W analyses of the temporary waste slope are presented in Table 501/3.

Table 501/3: Summary of Parameters Selected for Waste Analyses

Material	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (°)
Waste	10	5	25

2.4.4 Parameters Selected for Capping Analyses

The material parameters used in the analysis of the capping system are presented in Table 501/4. Conservative shear strength parameters have been used for the restoration soils.

Table 501/4: Summary of Parameters Selected for Capping Analyses

Material	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (°)
Restoration Soil	18	0	22

2.4.5 Parameters Selected for the Leachate Extraction System Analyses

The material parameters used in the analyses of the leachate extraction wells and monitoring points are presented in Table 501/5.

Table 501/5: Summary of Parameters Selected for Leachate Extraction System Analyses

Material	Unit Weight, (kN/m^3)	Undrained Shear Strength c_u (kPa)	Cohesion (kPa)	Friction Angle (°)
Concrete	24	-	-	-
Clay Liner	20	50	1	22
Drainage Gravel	18	-	0	30
Waste	10	-	-	-

2.5 Analyses

Three cross sections have been selected for slope stability and liner integrity assessment, the locations of which are shown on Figure 501/1 and Figure 501/2.

Section A represents typical cross sections for side slope sub-grade and liner stability analyses, as shown in Figure 501/1.

Section B is located through the critical temporary waste slopes, as shown in Figure 501/1.

Section C is located through the critical final waste slopes, as shown in Figure 501/2.

2.5.1 Side Slope Sub-Grade Analyses

A summary of the Slope/W runs for the sub-grade stability are presented in Table 503/6, and the output files are given in Appendix 501/1.

Table 501/6: Summary of Slope/W Runs for Side Slope Sub-Grade Analyses

File Reference	Description	Factor of Safety
Side Slope Subgrade 1	Section A, 1v:4h slope, circular failure, dry	1.96
Side Slope Subgrade 2	Section A, 1v:4h slope, circular failure, r_u=0.1	1.78
Side Slope Subgrade 3	Section A, 1v:4h slope, circular failure, r_u=0.2	1.60

2.5.2 Side Slope Liner Analyses

A summary of the Slope/W runs for the side slopes liner stability are presented in Table 501/7, and the output files are given in Appendix 501/2.

Table 501/7: Summary of Slope/W Runs for Side Slope Liner Analyses

File Ref	Description	Factor of Safety
Side Slope Liner 1	Section A, 1v:4h slope, circular failure, undrained	2.55
Side Slope Liner 2	Section A, 1v:4h slope, circular failure, drained, dry	2.00
Side Slope Liner 3	Section A, 1v:4h slope, circular failure, drained, r_u=0.1	1.82
Side Slope Liner 4	Section A, 1v:4h slope, circular failure, drained, r_u=0.2	1.63

2.5.3 Waste Analyses

A summary of the Slope/W runs for the temporary and final waste slopes is presented in Table 501/8, and the output files are given in Appendix 501/3.

Table 501/8: Summary of Slope/W Runs for Waste Analyses

File Ref	Description	Factor of Safety
Temporary Waste 1	Section B, 1v:2h slope, circular failure, dry	1.39
Temporary Waste 2	Section B, 1v:2h slope, circular failure, 1m leachate level	1.37
Temporary Waste 3	Section B, 1v:2h slope, circular failure, 2m leachate level	1.29
Temporary Waste 4	Section B, 1v:2h slope, circular failure, 1m leachate level, r_u=0.2	1.30
Final Waste 1	Section B, 1v:7h slope, circular failure, 1m leachate level	4.22
Final Waste 2	Section B, 1v:7h slope, circular failure, 1m leachate level, r_u=0.1	3.91
Final Waste 2	Section B, 1v:7h slope, circular failure, 1m leachate level, r_u=0.2	3.59

2.5.4 Capping Analyses

Infinite slope analysis has been carried out for the clay capping systems in order to calculate the stability of the restoration soils. A summary of the factors of safety calculated for the infinite slope analyses is presented in Table 501/9, and the output files are given in Appendix 501/4.

Table 501/9: Summary of Capping Analysis Results

Analysis Reference	Description	Factor of Safety
Capping Analysis 1	Section B, 1v:7h slope, 1m restoration soil, dry	2.84
Capping Analysis 2	Section B, 1v:7h slope, 1m restoration soil, 0.5m water table	2.07
Capping Analysis 3	Section B, 1v:7h slope, 1m restoration soil, 1m water table	1.29

2.5.5 Leachate Extraction System Analyses

Extraction Well Foundation

A summary of the foundation bearing capacity analysis and differential settlement calculated for the leachate extraction well is presented in Table 501/10, and the calculations sheets are given in Appendix 501/5.

Table 501/10: Summary of Leachate Extraction Well Foundation Analyses

Description	Factor of Safety		Differential Settlement (mm)
	Total Stress	Effective Stress	
Leachate extraction wells with 3 x 3 x 0.3 m concrete base and 18 m total height	1.9	16.2	4.1

Leachate Pipework Deflection

A summary of the leachate pipe work deflection calculations is presented in Table 501/11, and the calculation sheets are given in Appendix 501/6.

Table 501/11: Summary of Leachate Pipework Deflection Calculations

Description	Deflection	
	(mm)	(%)
Leachate pipe with a diameter of 180 mm	4.39	2.4

2.6 Assessment

2.6.1 Side Slope Subgrade Assessment

The analyses of the side slope sub-grade for Section A show that the factors of safety against circular failure under the dry conditions is 1.96. When the side slope is analysed with r_u values of 0.1 and 0.2, the factors of safety reduce to 1.78 and 1.60 respectively. The side slope sub-grade stability is therefore considered satisfactory.

2.6.2 Side Slope Liner Assessment

The analysis of the side slope liner using undrained shear strength parameters for the clay liner indicates that factor of safety against circular failure is 2.55. When effective stress parameters are used, the factor of safety calculated for dry conditions is 2.00. When pore water pressure build-up scenarios equivalent to r_u values of 0.1 and 0.2 are introduced to the clay liner, engineered fill and the in situ ground the factors of safety against circular failure reduce to 1.82 and 1.63 respectively. The side slope liner stability is therefore considered satisfactory.

2.6.3 Waste Assessment

For the proposed 1v:2h temporary waste slope in the extension cells, the factor of safety against circular failure is calculated as 1.39 for a dry condition. When a 1 m leachate level which is the compliance level, the calculated factor of safety slightly reduces to 1.37. With a 2 m leachate level, the calculated factor of safety further reduces to 1.29 which is still considered satisfactory. With pore water pressure build-up equivalent to r_u values of 0.2 and 1 m leachate level in place, the factor of safety are calculated as 1.30. Leachate recirculation is therefore considered acceptable provided that the leachate level is kept under the 1 m compliance level.

2.6.4 Capping Assessment

The capping analyses indicate that the factor of safety of the restoration soil stability is 2.84 for the dry conditions. When the restoration soil is half saturated (i.e. 0.5 m water table), the factor of safety reduces to 2.07. When the restoration soil becomes fully saturated (i.e. 1.0 m water table), the factor of safety further reduces to 1.29. This is still considered satisfactory. Although the restoration soil stays stable even under the fully saturated condition, it is a good practice to put good surface water management system in place on site to keep the restoration soil in relatively dry conditions.

2.6.5 Leachate Extraction System Assessment

Leachate Extraction Well Foundation

Calculations carried out to assess the bearing capacity of the clay liner beneath the leachate extraction well concrete bases with the proposed increased landfill height indicate that the factors of safety for both total and effective stress are above 1.5, which are considered satisfactory. The calculated differential settlement for the leachate extraction well is 2.1 mm which is considered to be satisfactory.

Leachate Pipework Deflection

Calculations carried to assess the 180 mm diameter leachate pipework indicate that the maximum deflection is 2.2% which is considered acceptable.

3.0 STABILITY MONITORING

3.1 Basal Sub-Grade Monitoring

Basal sub-grade monitoring is not deemed necessary. However, the surface layer condition of the basal sub-grade should be carefully inspected prior to construction of the clay liner.

3.2 Side Slope Sub-Grade Monitoring

The side slopes sub-grade system should be visually monitored during construction for any signs of groundwater ingress. Site-specific shear strength testing should be undertaken to verify that the materials on-site are in accordance with the parameters used within this assessment.

3.3 Basal Lining System Monitoring

Site-specific shear strength testing should be undertaken to verify that the materials on site are in accordance with the parameters used within this assessment.

3.4 Side Slope Lining System Monitoring

Site-specific shear strength testing should be undertaken to verify that the materials on site are in accordance with the parameters used within this assessment.

3.5 Waste Mass Monitoring

The temporary waste slopes in the extension cells will have a gradient not greater than 1v:2h. If temporary blinding is applied to exposed waste faces between cells it is recommended that this is removed prior to placement of subsequent waste against these slopes. The temporary waste slopes should be monitored for signs of instability on a weekly basis and immediately after any heavy rainfall period.

3.6 Capping System Monitoring

The capping system should be monitored for signs of slumping in the restoration soils. The capping slopes should be monitored for signs of instability on a weekly basis and immediately after any heavy rainfall period.

4.0 REFERENCES

1) Environment Agency (2003). *'Stability of Landfill Lining Systems: Report No 2 Guidance'*, R & D Technical Report, Ref. P1-385/TR2, 2003.
2) Hafrenwater (2018). Conceptual Site Model, Environmental Setting and Site Design Report (ESSD), Park Grounds Landfill, June 2018.
3) AK Environmental (2012). Cell 7 CQA Plan Rev D, Park Grounds Landfill Wiltshire, May 2012.
4) Waterman Transport & Development Ltd (2014). Cell 8 CQA Report, Park Grounds Landfill, September 2014.
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6) D R V Jones, D Taylor & N Dixon (1997), *Shear Strength of Waste and its use in Landfill Stability Analysis. Proc. Geoenvironmental Engineering conf.*, Yong & Thomas (eds.), Thomas Telford, London, pp. 343-350.

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Golder Associates (UK) Ltd

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Principal

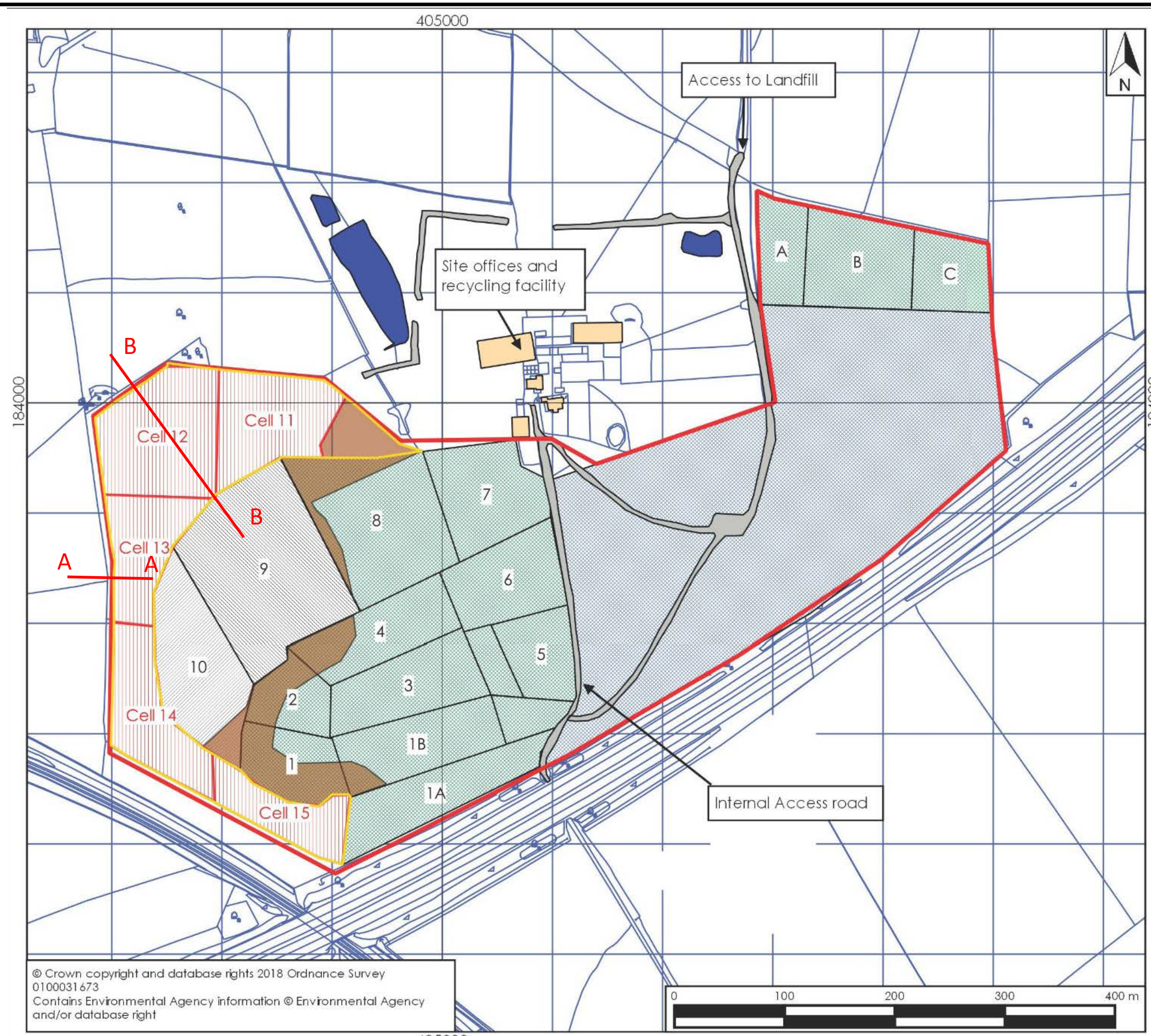
Date: 3 July 2018

BZ/DRVJ/ab

FIGURES

Figure 501/1: Location of Cross Sections A&B

Figure 501/2: Location of Cross Section C



Client	Crapper and Sons Landfill Ltd	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
Project	Park Grounds Landfill Stability Risk Assessment	File No.: 1894134.501		Project No.: 1894134	
		Size: A4	Scale: Not to Scale	Status: Report Issue	
Title	Figure 501/1: Location of Cross Sections A&B	Drawing No.: Figures			

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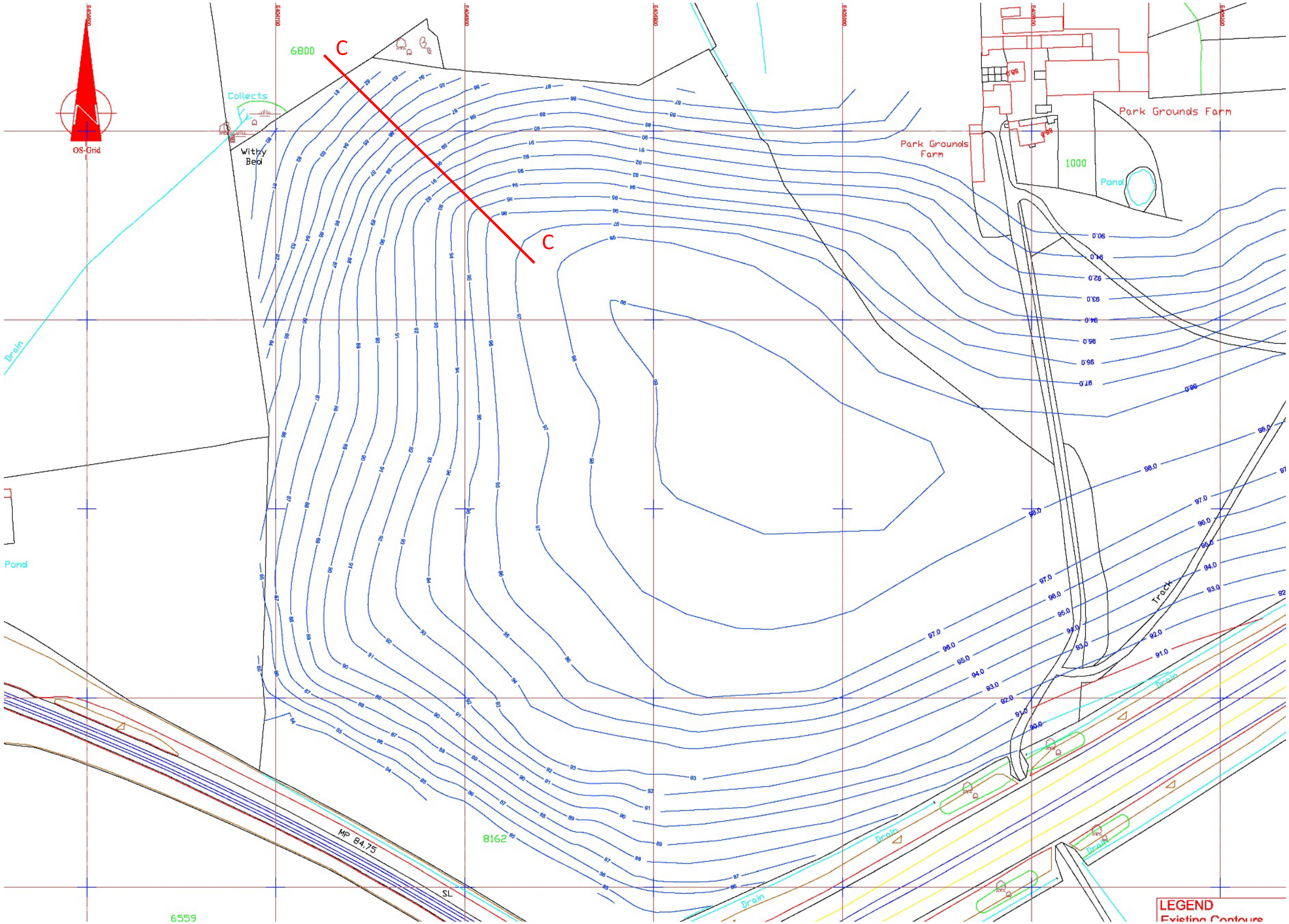


Client	**Crapper and Sons Landfill Ltd**
Project	**Park Grounds Landfill Stability Risk Assessment**
Title	**Figure 501/2: Location of Cross Sections C**

Created by	Project Manager	Reviewer	Date
BZ	BZ	DRVJ	28.06.18

File No.	Project No.
1894134.501	1894134

Size	Scale	Status
A4	Not to Scale	Report Issue

Drawing No. **Figures**

Golder Associates

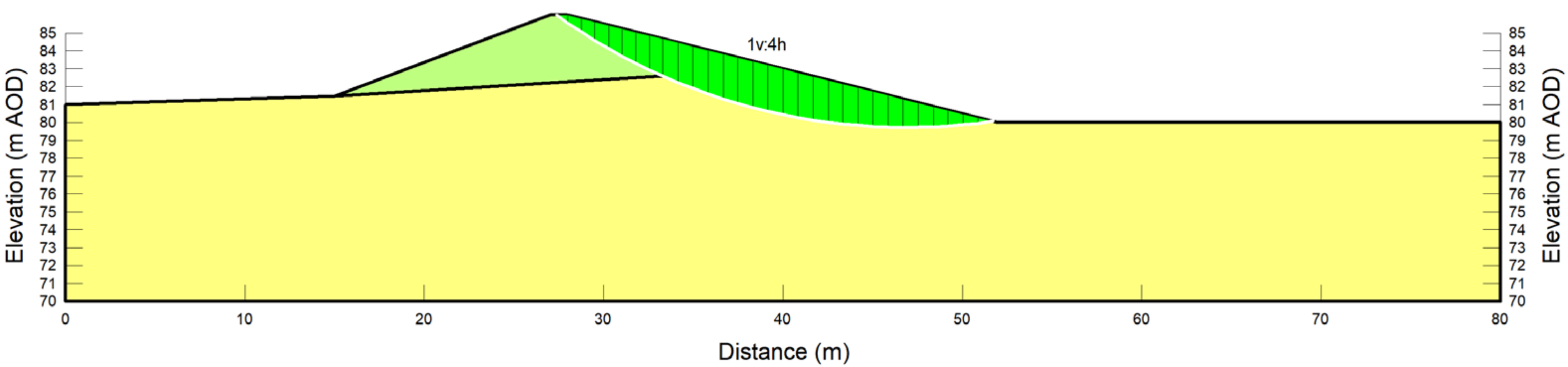
APPENDIX 501/1

Side Slope Sub-Grade Analyses

1.956

Project: Park Grounds SRA
Run ID: Side Slope Subgrade 1
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Engineered Fill	Mohr-Coulomb	20	1	22
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22

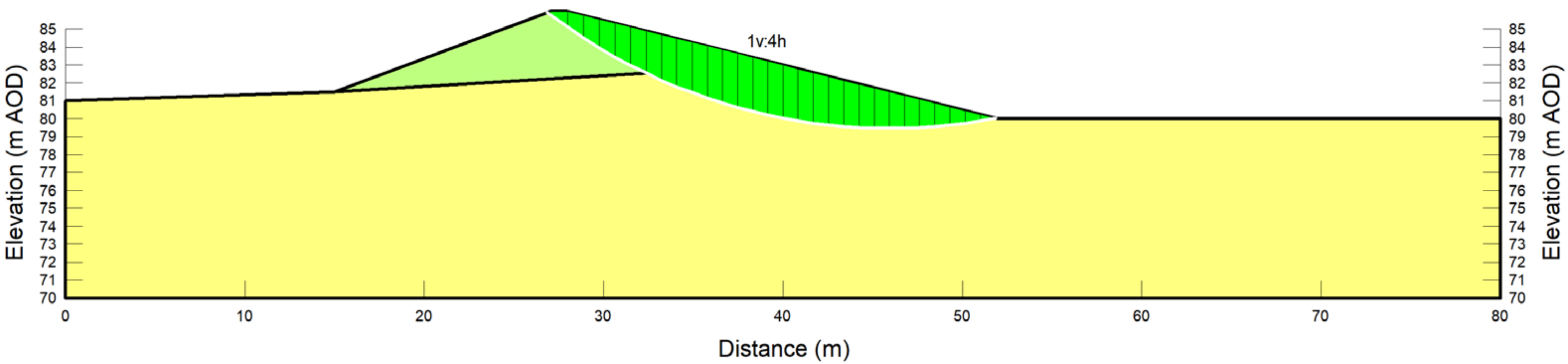


Golder Associates	Client: **Crapper and Sons Landfill Ltd**	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
	Project: **Park Grounds Landfill Stability Risk Assessment**	File No.: 1894134.501		Project No.: 1894134	
		Size: A4	Scale: Not to Scale	Status: Report Issue	
© Golder Associates (UK) Ltd	Title: **Side Slope Subgrade Analysis 1, Dry**	Drawing No.: **Appendix 501/1**			

1.782

Project: Park Grounds SRA
Run ID: Side Slope Subgrade 2
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Ru
(green)	Engineered Fill	Mohr-Coulomb	20	1	22	0.1
(yellow)	In Situ Oxford Clay	Mohr-Coulomb	20	2	22	0.1



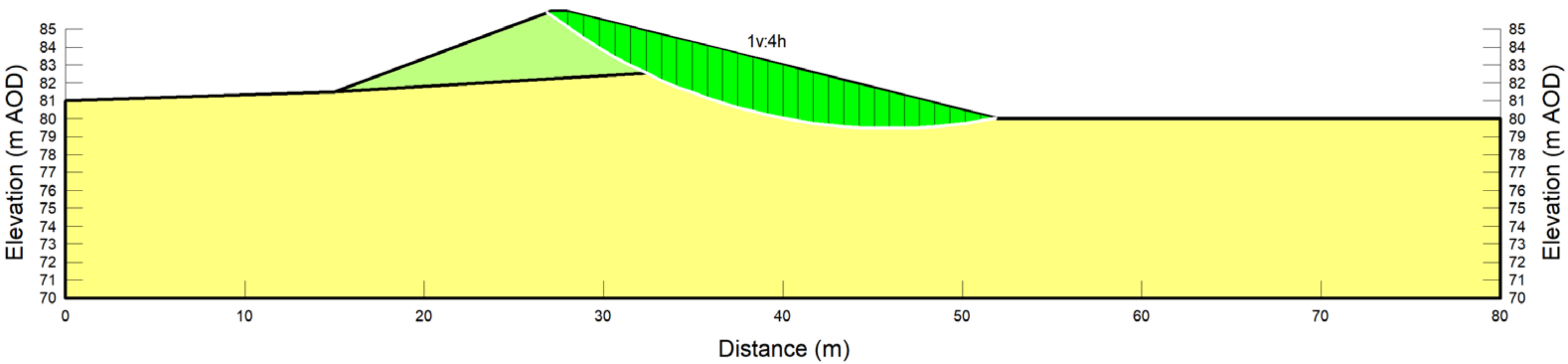
Client	Crapper and Sons Landfill Ltd	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
Project	Park Grounds Landfill Stability Risk Assessment	File No.: 1894134.501		Project No.: 1894134	
Title	**Side Slope Subgrade Analysis 2, r_u=0.1**	Size: A4	Scale: Not to Scale	Status: Report Issue	
		Drawing No.: **Appendix 501/1**			

Golder Associates

1.596

Project: Park Grounds SRA
Run ID: Side Slope Subgrade 3
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Ru
(green)	Engineered Fill	Mohr-Coulomb	20	1	22	0.2
(yellow)	In Situ Oxford Clay	Mohr-Coulomb	20	2	22	0.2



Client	Crapper and Sons Landfill Ltd	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ
				Date: 28.06.18
Project	Park Grounds Landfill Stability Risk Assessment	File No.: 1894134.501		Project No.: 1894134
		Size: A4	Scale: Not to Scale	Status: Report Issue
Title	Side Slope Subgrade Analysis 3, r_u=0.2	Drawing No.: Appendix 501/1		

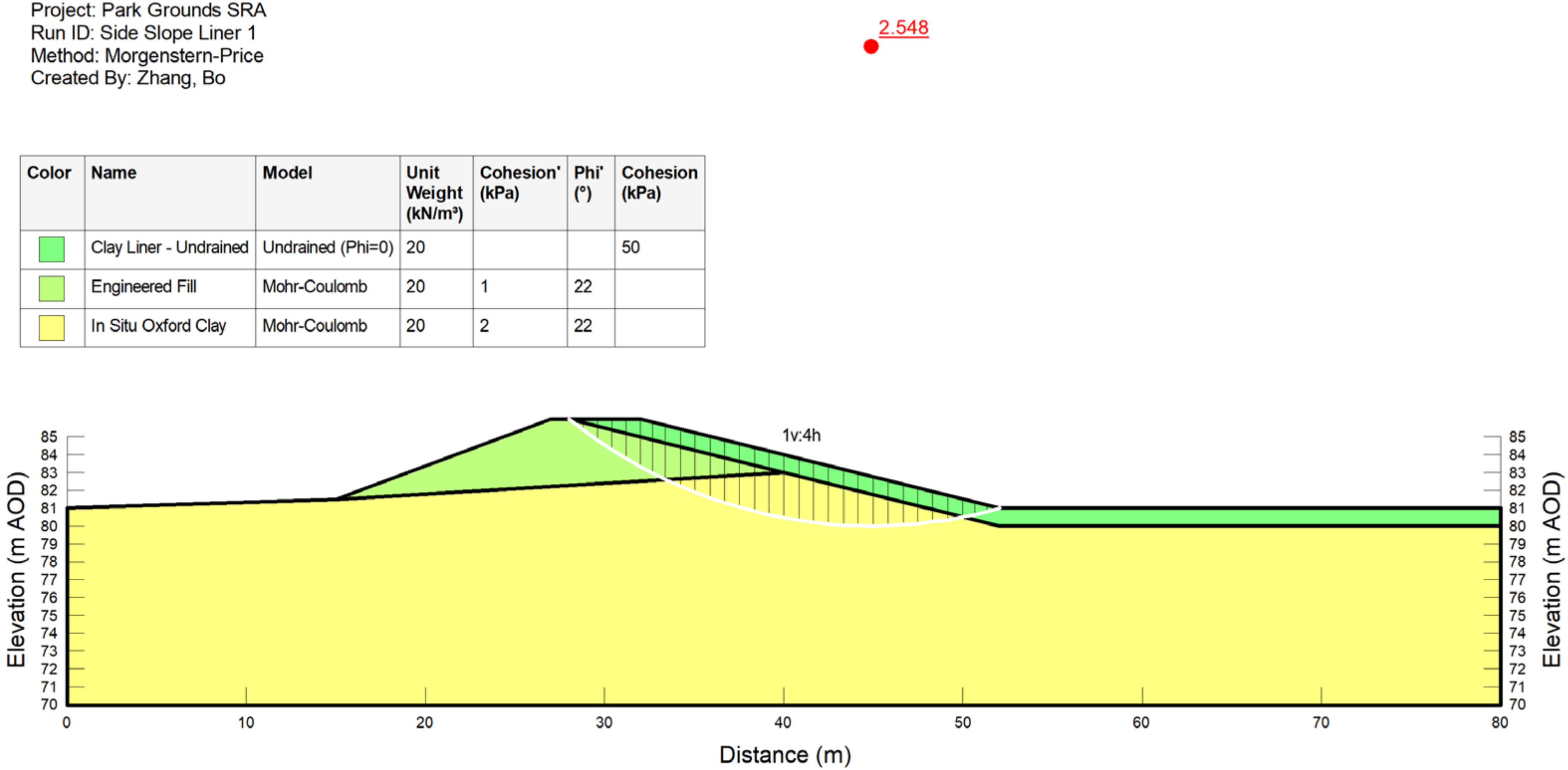
Golder Associates

APPENDIX 501/2

Side Slope Liner Analyses

Project: Park Grounds SRA
Run ID: Side Slope Liner 1
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion (kPa)
	Clay Liner - Undrained	Undrained (Phi=0)	20			50
	Engineered Fill	Mohr-Coulomb	20	1	22	
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22	

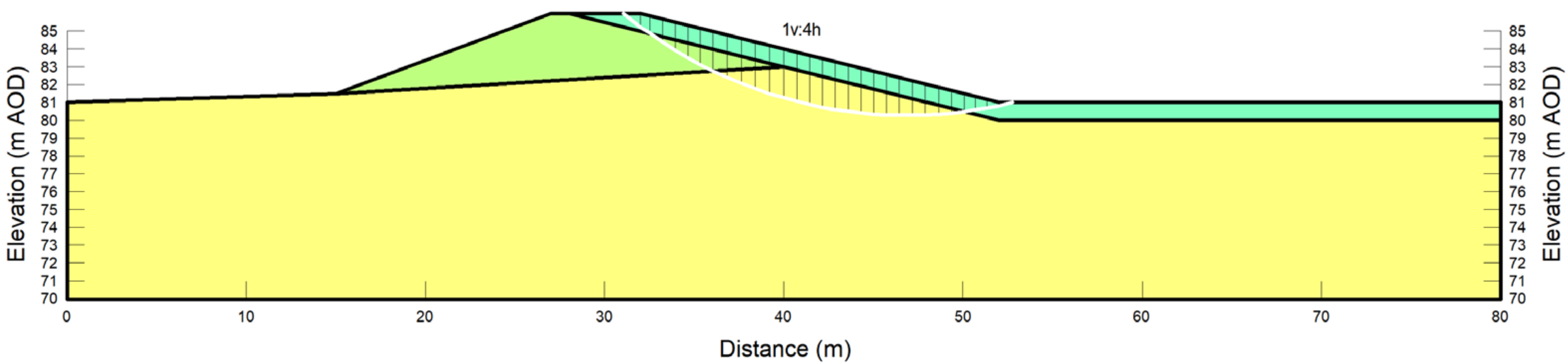


Client: **Crapper and Sons Landfill Ltd**	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
Project: **Park Grounds Landfill Stability Risk Assessment**	File No.: 1894134.501		Project No.: 1894134	
	Size: A4	Scale: Not to Scale	Status: Report Issue	
Title: **Side Slope Liner Analysis 1, Undrained**	Drawing No.: **Appendix 501/2**			

Golder Associates

Project: Park Grounds SRA
Run ID: Side Slope Liner 2
Method: Morgenstern-Price
Created By: Zhang, Bo

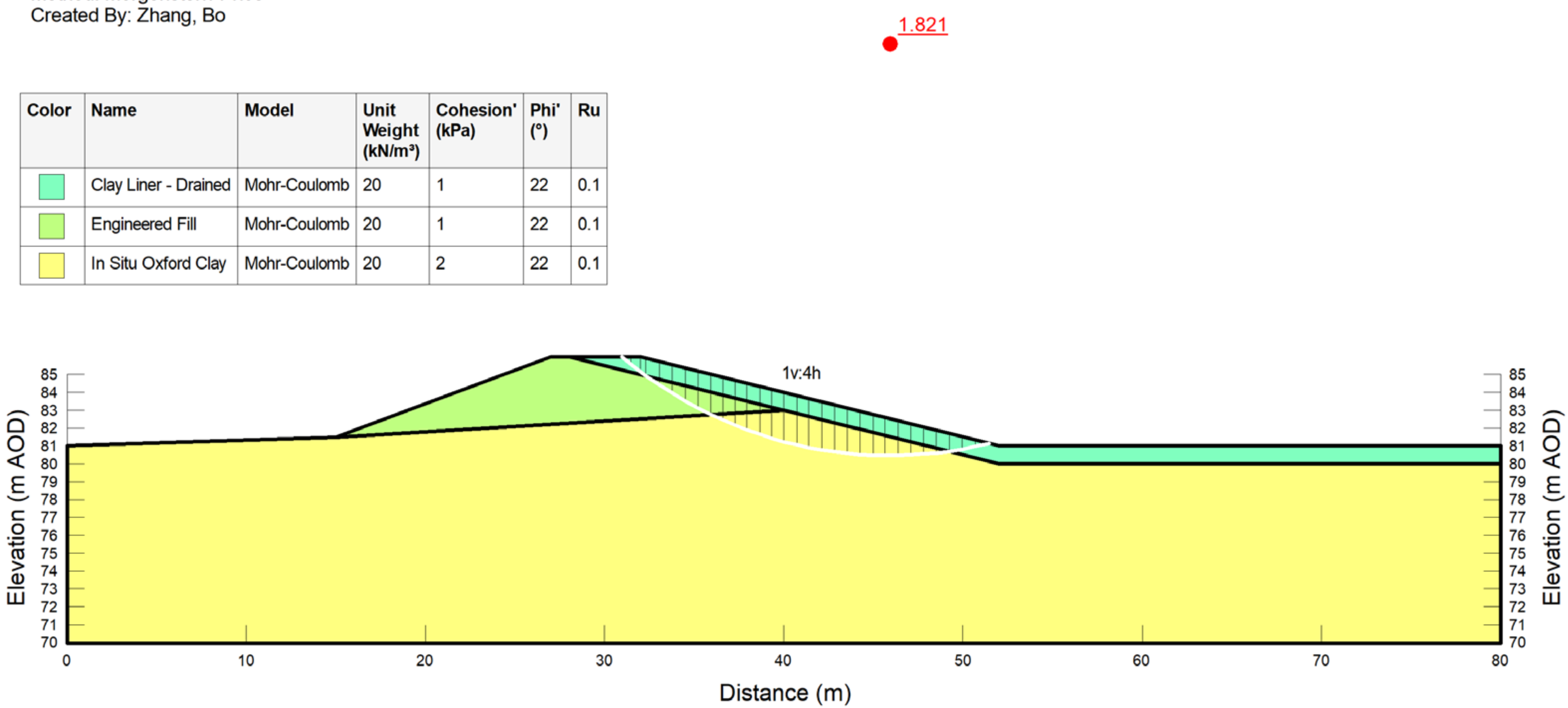
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Clay Liner - Drained	Mohr-Coulomb	20	1	22
	Engineered Fill	Mohr-Coulomb	20	1	22
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22



Client	Crapper and Sons Landfill Ltd	Created by BZ	Project Manager BZ	Reviewer DRVJ	Date 28.06.18
Project	Park Grounds Landfill Stability Risk Assessment	File No. 1894134.501		Project No. 1894134	
		Size A4	Scale Not to Scale	Status Report Issue	
Title	Side Slope Liner Analysis 2, Drained, Dry	Drawing No. Appendix 501/2			

Project: Park Grounds SRA
Run ID: Side Slope Liner 3
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Ru
	Clay Liner - Drained	Mohr-Coulomb	20	1	22	0.1
	Engineered Fill	Mohr-Coulomb	20	1	22	0.1
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22	0.1

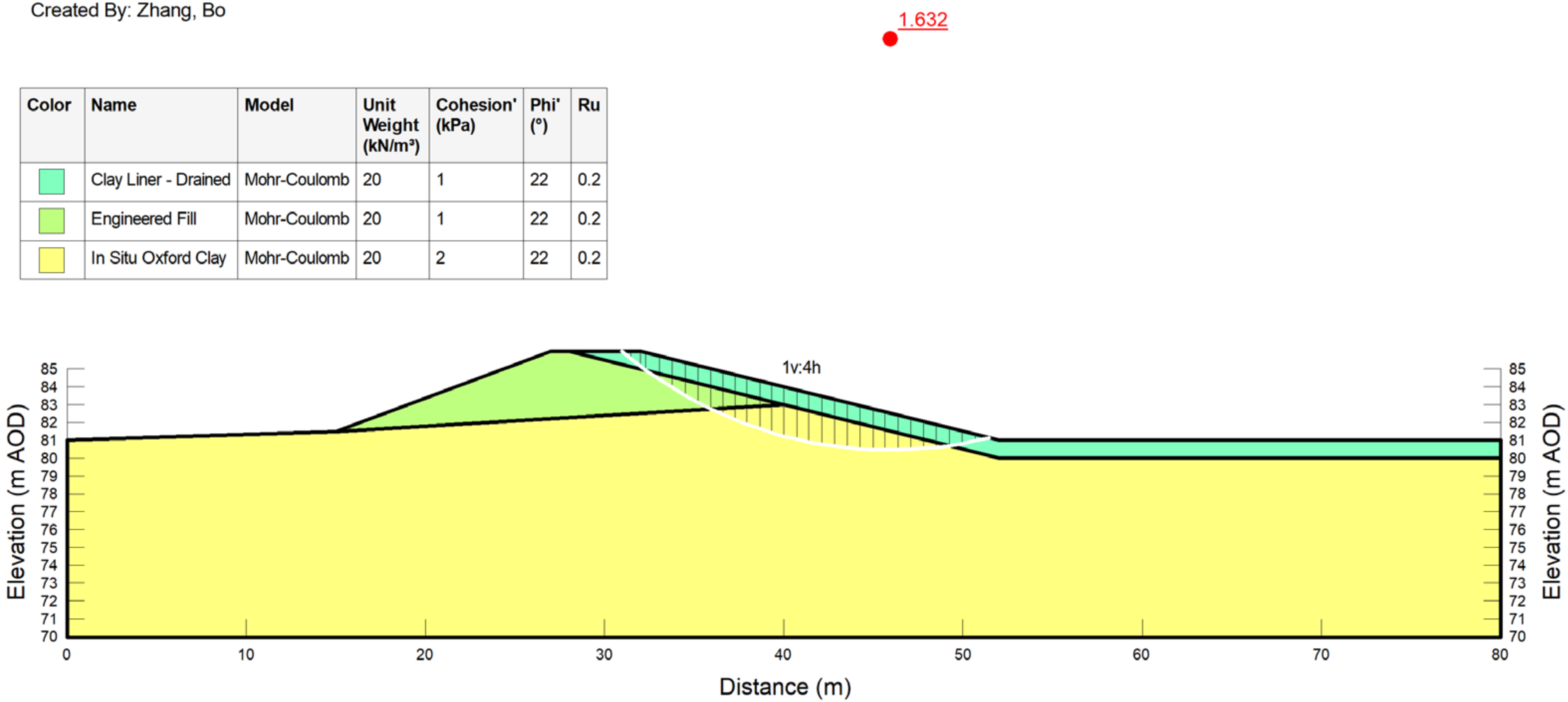


Client	Crapper and Sons Landfill Ltd
Project	Park Grounds Landfill Stability Risk Assessment
Title	Side Slope Liner Analysis 3, Drained, r_u=0.1

Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
File No.: 1894134.501		Project No.: 1894134	
Size: A4	Scale: Not to Scale	Status: Report Issue	
Drawing No.: Appendix 501/2			

Project: Park Grounds SRA
Run ID: Side Slope Liner 4
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Ru
	Clay Liner - Drained	Mohr-Coulomb	20	1	22	0.2
	Engineered Fill	Mohr-Coulomb	20	1	22	0.2
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22	0.2



Client	Crapper and Sons Landfill Ltd	Created by BZ	Project Manager BZ	Reviewer DRVJ	Date 28.06.18
Project	Park Grounds Landfill Stability Risk Assessment	File No. 1894134.501		Project No. 1894134	
		Size A4	Scale Not to Scale	Status Report Issue	
Title	Side Slope Liner Analysis 4, Drained, r_u=0.2	Drawing No. Appendix 501/2			

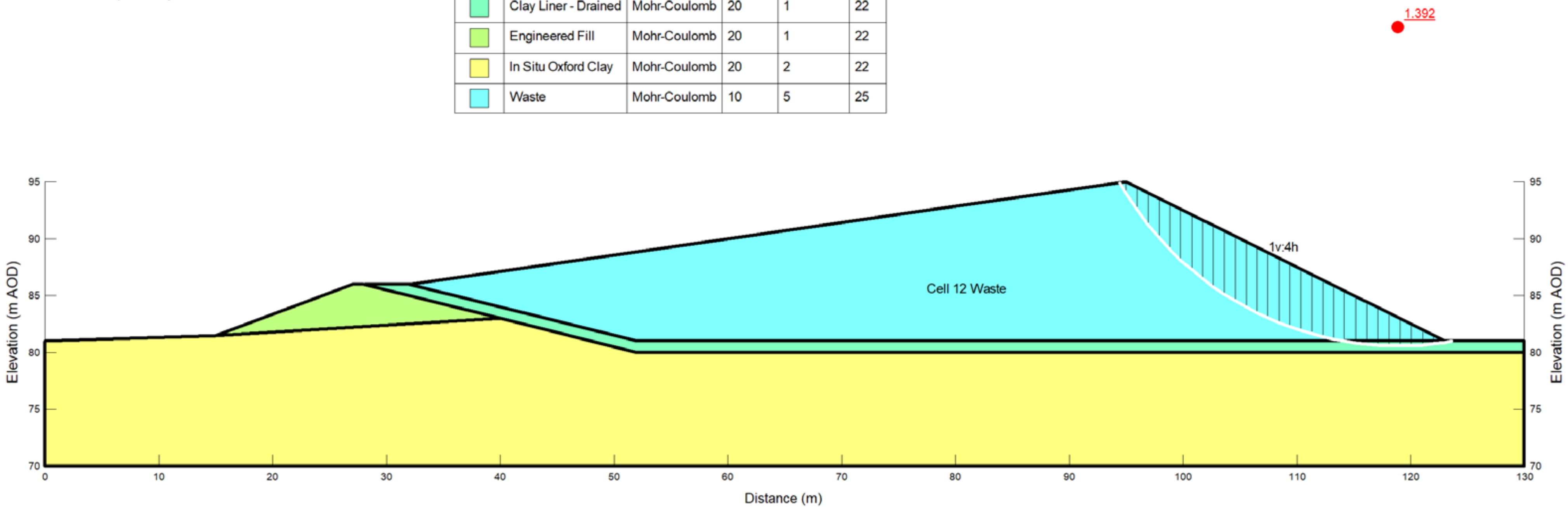
Golder Associates

APPENDIX 501/3

Waste Analyses

Project: Park Grounds SRA
Run ID: Temporary Waste 1
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Clay Liner - Drained	Mohr-Coulomb	20	1	22
	Engineered Fill	Mohr-Coulomb	20	1	22
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22
	Waste	Mohr-Coulomb	10	5	25



Golder Associates

Client	Crapper and Sons Landfill Ltd
Project	Park Grounds Landfill Stability Risk Assessment
Title	Temporary Waste Analysis 1, Dry

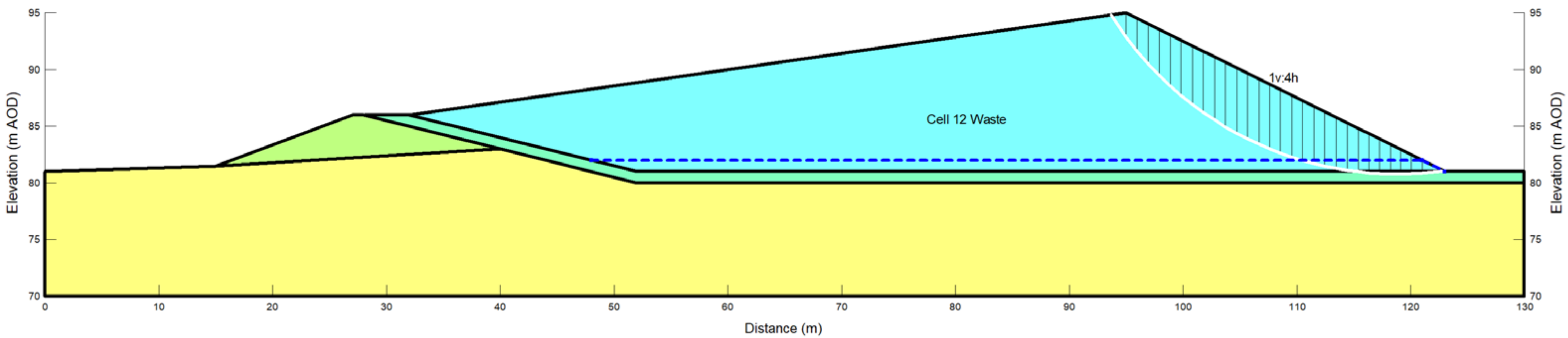
Created by	Project Manager	Reviewer	Date
BZ	BZ	DRVJ	28.06.18

File No. 1894134.501	Project No. 1894134
Size A4 / Scale Not to Scale	Status Report Issue
Drawing No. Appendix 501/3	

Project: Park Grounds SRA
Run ID: Temporary Waste 2
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m^3)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Liner - Drained	Mohr-Coulomb	20	1	22	
	Engineered Fill	Mohr-Coulomb	20	1	22	
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22	
	Waste	Mohr-Coulomb	10	5	25	1

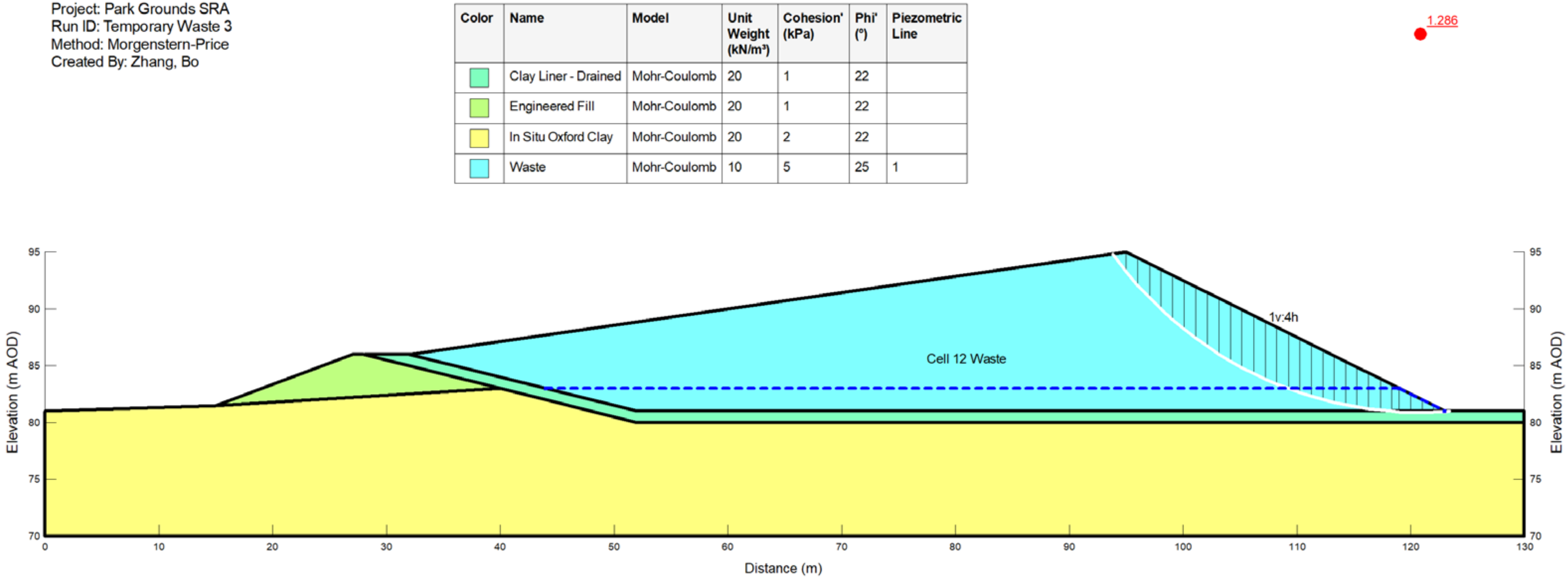
1.367



Golder Associates	Client: Crapper and Sons Landfill Ltd	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
	Project: Park Grounds Landfill Stability Risk Assessment	File No.: 1894134.501		Project No.: 1894134	
		Size: A4	Scale: Not to Scale	Status: Report Issue	
	Title: Temporary Waste Analysis 2, 1m leachate	Drawing No.: Appendix 501/3			

Project: Park Grounds SRA
Run ID: Temporary Waste 3
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Liner - Drained	Mohr-Coulomb	20	1	22	
	Engineered Fill	Mohr-Coulomb	20	1	22	
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22	
	Waste	Mohr-Coulomb	10	5	25	1

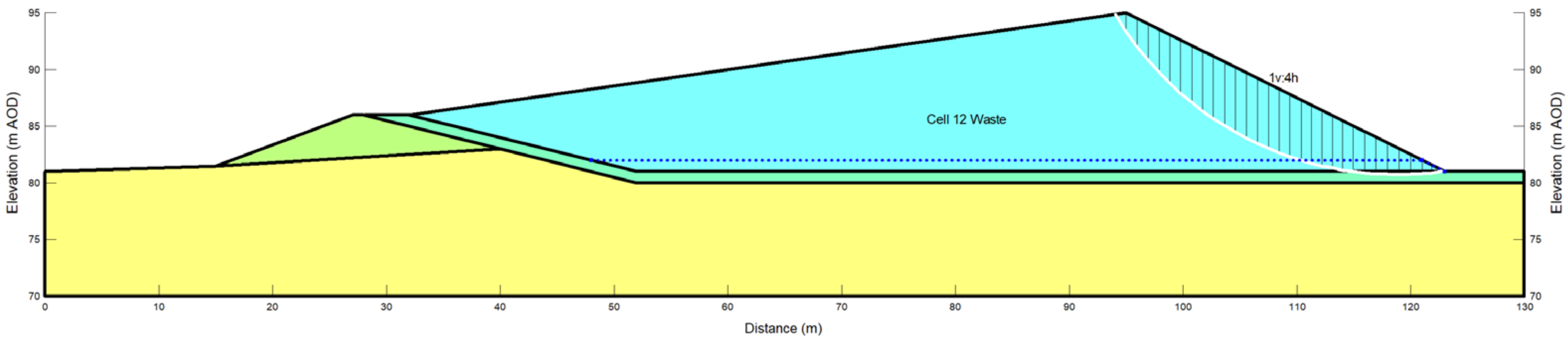


Golder Associates	Client: **Crapper and Sons Landfill Ltd**	Created by: BZ · Project Manager: BZ · Reviewer: DRVJ · Date: 28.06.18
	Project: **Park Grounds Landfill Stability Risk Assessment**	File No.: 1894134.501 · Project No.: 1894134
		Size: A4 · Scale: Not to Scale · Status: Report Issue
	Title: **Temporary Waste Analysis 3, 2m leachate**	Drawing No.: **Appendix 501/3**

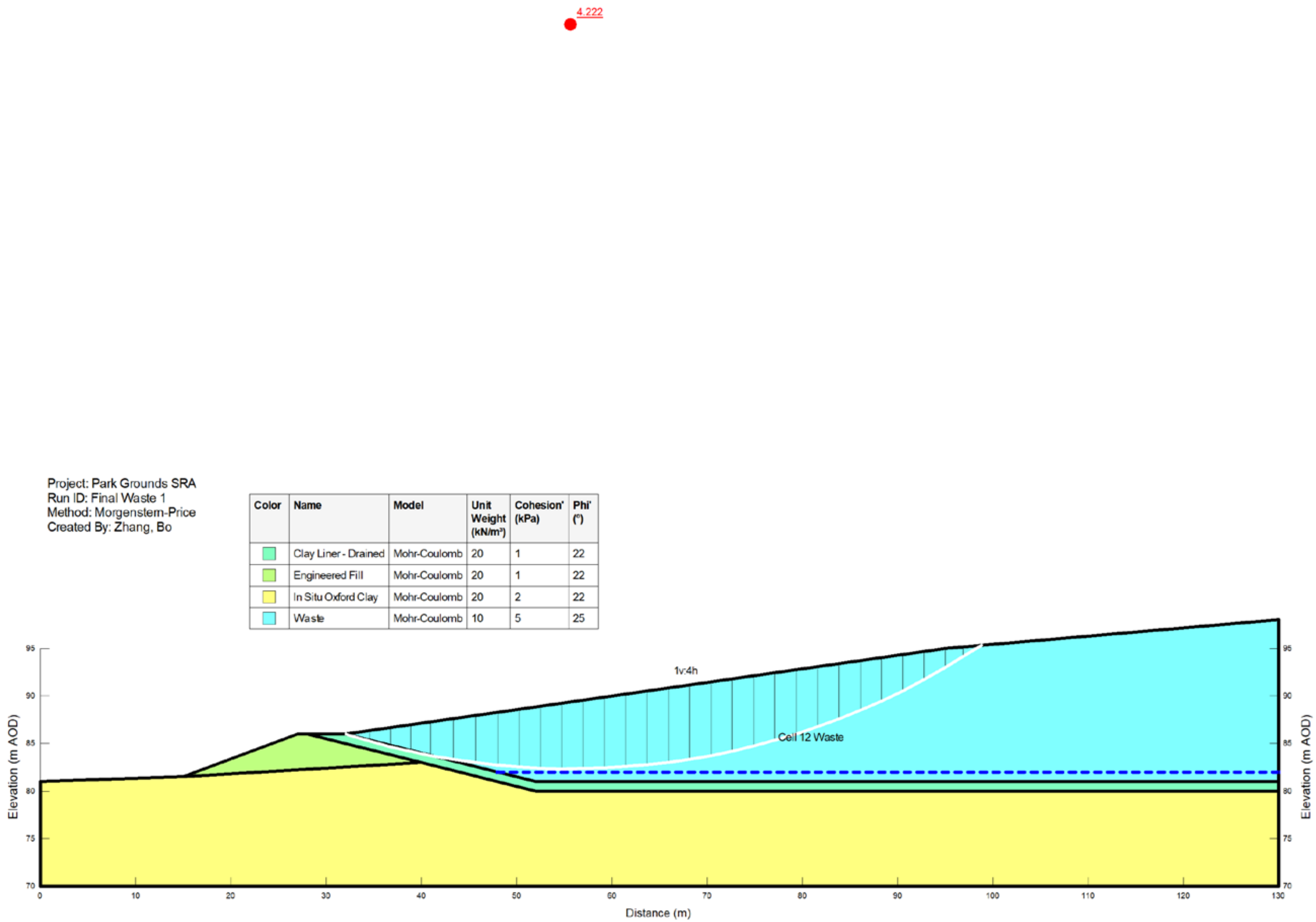
Project: Park Grounds SRA
Run ID: Temporary Waste 4
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line	Ru	Include Ru in PWP
	Clay Liner - Drained	Mohr-Coulomb	20	1	22			No
	Engineered Fill	Mohr-Coulomb	20	1	22			No
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22			No
	Waste	Mohr-Coulomb	10	5	25	1	0.2	Yes

1.297



Golder Associates	Client: **Crapper and Sons Landfill Ltd**	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
	Project: **Park Grounds Landfill Stability Risk Assessment**	File No.: 1894134.501		Project No.: 1894134	
	Title: **Temporary Waste Analysis 3, 1m leachate, r_u=0.2**	Size: A4	Scale: Not to Scale	Status: Report Issue	
		Drawing No.: **Appendix 501/3**			



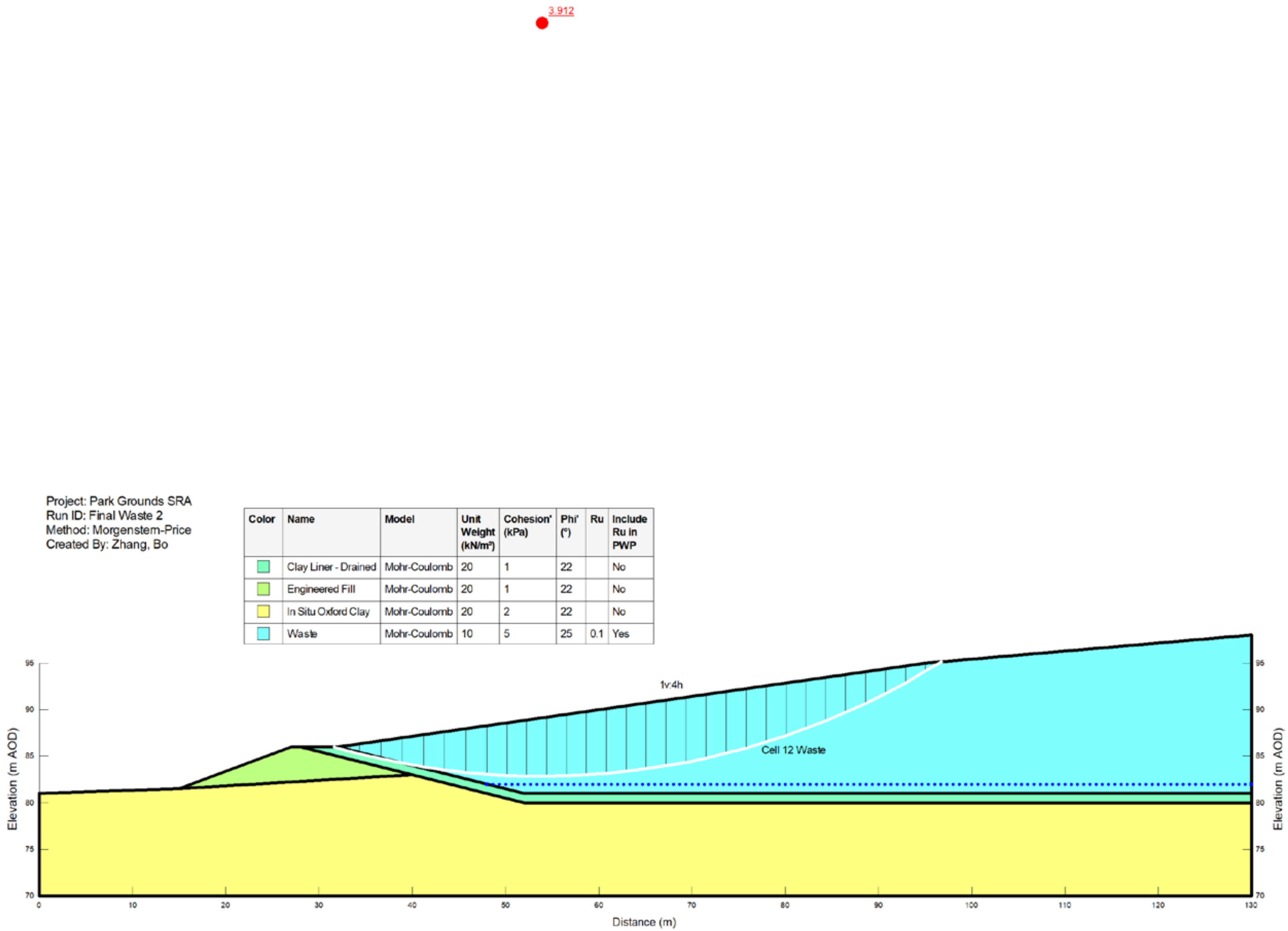
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Clay Liner - Drained	Mohr-Coulomb	20	1	22
	Engineered Fill	Mohr-Coulomb	20	1	22
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22
	Waste	Mohr-Coulomb	10	5	25

Golder Associates

Client	Crapper and Sons Landfill Ltd
Project	Park Grounds Landfill Stability Risk Assessment
Title	Final Waste Analysis 1, 1m leachate
Created by	BZ
Project Manager	BZ
Reviewer	DRVJ
Date	28.06.18
File No.	1894134.501
Project No.	1894134
Size	A4
Scale	Not to Scale
Status	Report Issue
Drawing No.	Appendix 501/3

Project: Park Grounds SRA
Run ID: Final Waste 2
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Ru	Include Ru in PWP
	Clay Liner - Drained	Mohr-Coulomb	20	1	22		No
	Engineered Fill	Mohr-Coulomb	20	1	22		No
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22		No
	Waste	Mohr-Coulomb	10	5	25	0.1	Yes

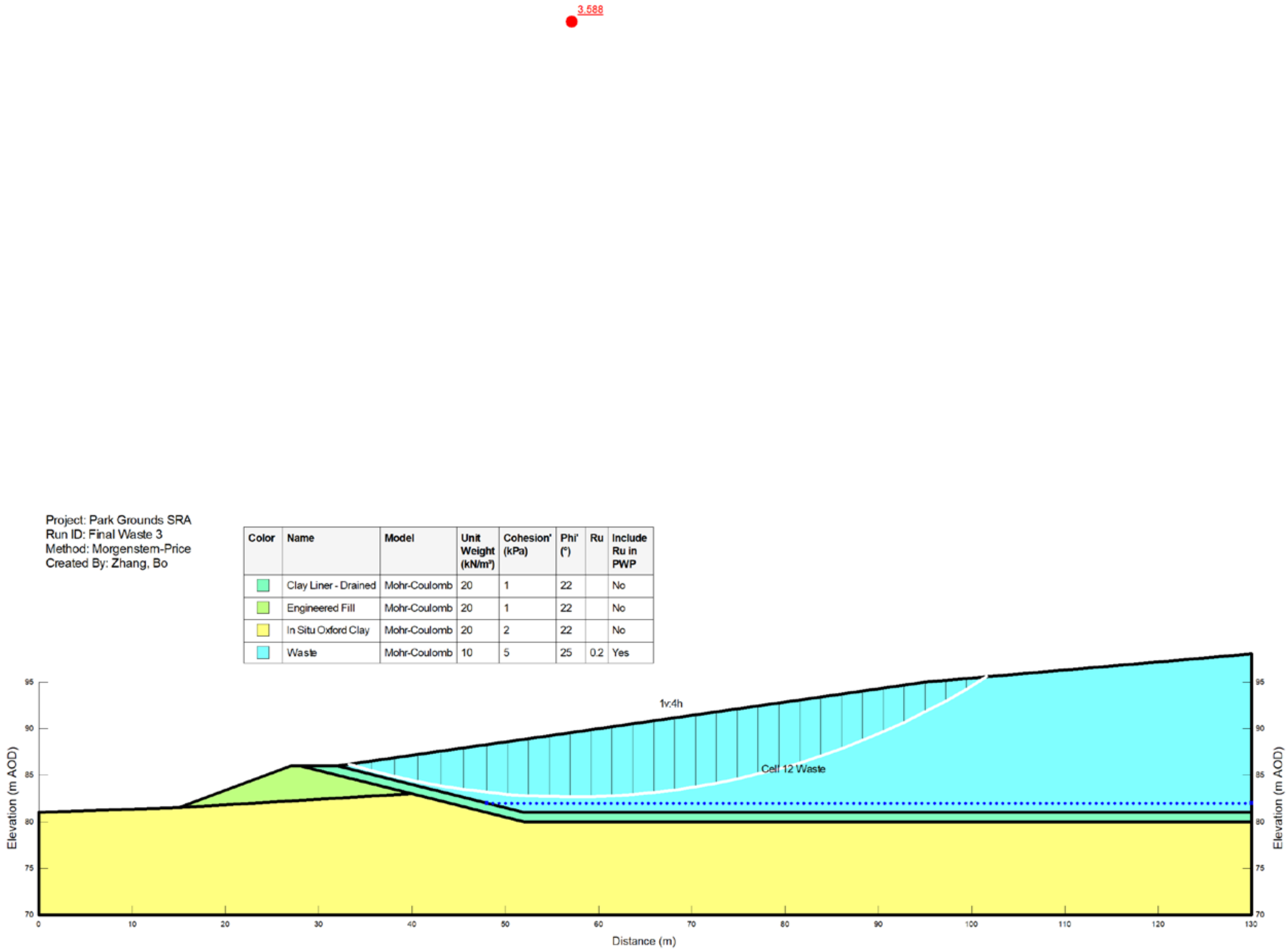


Client	Crapper and Sons Landfill Ltd	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
Project	Park Grounds Landfill Stability Risk Assessment	File No.: 1894134.501		Project No.: 1894134	
		Size: A4	Scale: Not to Scale	Status: Report Issue	
Title	Final Waste Analysis 2, 1m leachate, r_u=0.1	Drawing No.: Appendix 501/3			

Golder Associates

Project: Park Grounds SRA
Run ID: Final Waste 3
Method: Morgenstern-Price
Created By: Zhang, Bo

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Ru	Include Ru in PWP
	Clay Liner - Drained	Mohr-Coulomb	20	1	22		No
	Engineered Fill	Mohr-Coulomb	20	1	22		No
	In Situ Oxford Clay	Mohr-Coulomb	20	2	22		No
	Waste	Mohr-Coulomb	10	5	25	0.2	Yes



Client: **Crapper and Sons Landfill Ltd**	Created by: BZ	Project Manager: BZ	Reviewer: DRVJ	Date: 28.06.18
Project: **Park Grounds Landfill Stability Risk Assessment**	File No.: 1894134.501		Project No.: 1894134	
	Size: A4	Scale: Not to Scale	Status: Report Issue	
Title: **Final Waste Analysis 3, 1m leachate r_u=0.2**	Drawing No.: **Appendix 501/3**			

APPENDIX 501/4

Capping Analyses

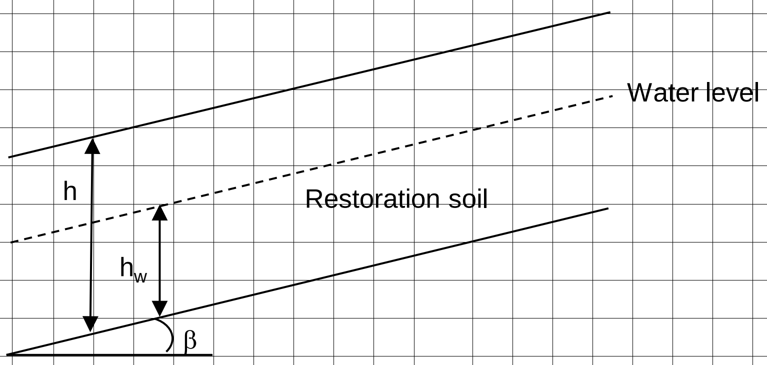
PROJECT	Park Grounds Landfill Stability Risk Assessment		
Job No. 1894134	Made By: BZ	Date: 28/06/2018
Ref. Appendix 501/4	Checked: DRVJ	Sheet: 1
	Reviewed: DRVJ	of: 3

Clay Capping System Restoration Soil Stability

Aim: To assess the stability of the capping system and restoration soils.

Approach: Use the infinite slope approach.

Geometry:



Input Parameters

Cover soil unit weight, γ	18	kN/m^3
Cover soil internal shear strength, ϕ	22	Deg.
Cover soil cohesion, c	0	kPa
Unit weight of water, γ_w	9.81	kN/m^3
Thickness of cover soil (vertical), h	1.00	m
Piezometric water level, h_w	0.00	m
Slope angle, β	8.1	Deg.

Calculations

Factor of safety against translational failure is given by:

$$F = \frac{c' + (\gamma h - \gamma_w h_w)\cos^2\beta \tan\phi'}{\gamma h \sin\beta \cos\beta}$$

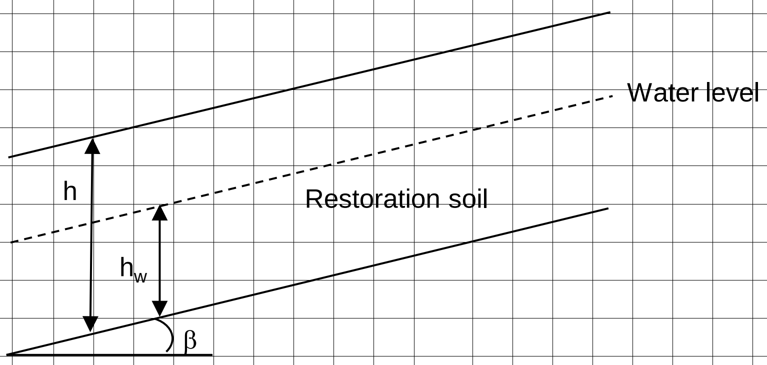
$$F = \frac{7.13}{2.51} \quad 2.84$$

Clay Capping System Restoration Soil Stability

Aim: To assess the stability of the capping system and restoration soils.

Approach: Use the infinite slope approach.

Geometry:



Input Parameters

Cover soil unit weight, γ	18	kN/m^3
Cover soil internal shear strength, ϕ	22	Deg.
Cover soil cohesion, c	0	kPa
Unit weight of water, γ_w	9.81	kN/m^3
Thickness of cover soil (vertical), h	1.00	m
Piezometric water level, h_w	0.50	m
Slope angle, β	8.1	Deg.

Calculations

Factor of safety against translational failure is given by:

$$F = \frac{c' + (\gamma h - \gamma_w h_w)\cos^2\beta \tan\phi'}{\gamma h \sin\beta \cos\beta}$$

$$F = \frac{5.19}{2.51} \qquad 2.07$$

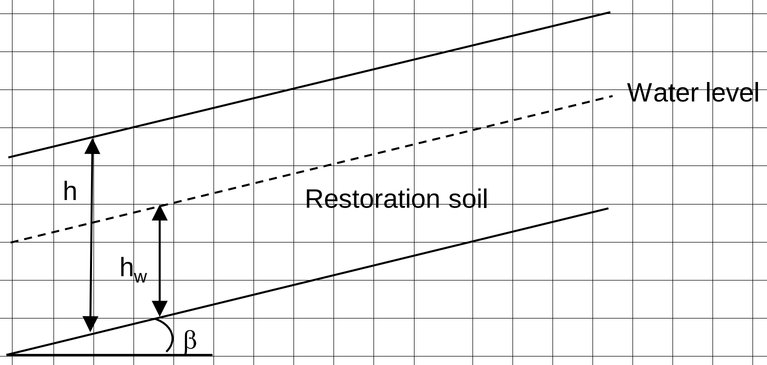
Golder Associates	**PROJECT** **Park Grounds Landfill Stability Risk Assessment**	
Job No. 1894134	Made By: BZ	Date: 24/04/2018
Ref. Appendix 501/4	Checked: DRVJ	Sheet: 3
	Reviewed: DRVJ	of: 3

Clay Capping System Restoration Soil Stability

Aim: To assess the stability of the capping system and restoration soils.

Approach: Use the infinite slope approach.

Geometry:



Input Parameters

Cover soil unit weight, γ	18	kN/m^3
Cover soil internal shear strength, φ	22	Deg.
Cover soil cohesion, c	0	kPa
Unit weight of water, γ_w	9.81	kN/m^3
Thickness of cover soil (vertical), h	1.00	m
Piezometric water level, h_w	1.00	m
Slope angle, β	8.1	Deg.

Calculations

Factor of safety against translational failure is given by:

$$F = \frac{c' + (\gamma h - \gamma_w h_w)\cos^2\beta \tan\phi'}{\gamma h \sin\beta \cos\beta}$$

$$F = \frac{3.24}{2.51} \qquad 1.29$$

APPENDIX 501/5

Leachate Extraction Well Foundation Analyses

Aim: Establish the stability and servicebility of the leachate extraction and monitoring wells.

Background: The leachate extraction wells comprise 0.9 m internal diameter, reinforced concrete chamber.

The base comprises a 300 mm thick, 3000 mm square concrete slab.

The leachate well will be built up with the waste, with a maximum height of 18 m (including 1.0 m of drainage gravel on top of the slab and 1.0 m of restoration soils).

Approach: Assess the bearing capacity and differential settlement under loading.

Assumptions:

Unit weight of concrete, γ_{conc}		=	24	kN/m^3
Unit weight of clay, γ_{BES}		=	20	kN/m^3
Unit weight of gravel, γ_{gravel}		=	18	kN/m^3
Unit weight of restoration soils, γ_{rest}		=	18	kN/m^3
Unit weight of waste, γ_{waste}		=	10	kN/m^3
Shear strength of the clay liner (total stress), c_u		=	50	kPa
Shear strength of the clay liner (effective stress),	c'	=	1	kPa
	ϕ'	=	22	degrees
Friction angle between waste and concrete, δ=			12	degrees
Waste coefficient, $K_{waste}(\sigma_h'/\sigma_v')$		=	0.4	

Calculations:

1. Loading from various components

(a) Self weight of concrete chamber

Internal diameter	=	0.9	m
Wall thickness	=	0.1	m
External diameter	=	1.1	m
Final height	=	18	m
Waste Height	=	16	m
Unit weight of concrete	=	24	kN/m^3

Load = $(\pi/4)h(D^2_e - D^2_i)\gamma_{conc}$

Load = **135.7** kN

(b) Concrete slab loading

3	x	**3**	m
Thickness	=	**0.3**	m
Unit weight of concrete	=	24	kN/m^3

Load = Volume x γ_{conc}

Load = **64.8** kN

PROJECT	Park Grounds Landfill Stability Risk Assessment		
Job No. 1894134	Made By: BZ	Date: 28/06/2018	
Ref. Appendix 501/5	Checked: DRVJ	Sheet: 2	
	Reviewed: DRVJ	of: 7	

Calculations:

Loading from various components (Cont'd.)

(c) Waste load on extraction slab

Slab area = 9 m^2

Th Pipe area = π x D_e^2 / 4 = 0.95 m^2

Load = (slab area - pipe area) x height x γ_{waste}

Load = **1,287.9** kN

(d) Gravel load on extraction slab

Load = (slab area - pipe area) x thickness x γ_{gravel}

Gravel Thickness = 1 m

Load = **144.9** kN

(e) Cap and Restoration load on extraction slab

Load = (slab area - pipe area) x ((cap thickness x $\gamma_{cap)}$ + (restoration thickness x γ_{rest}))

Mineral Cap thickness = 1 m

Restoration Thickness = 1 m

Load = **305.9** kN

(f) Negative skin friction loading on concrete pipe

NSF is given by $\sigma_h' \tan\delta$, where $\sigma_h' = K_{waste} . \sigma_v'$

NSF = $(K_{waste} \cdot \sigma_{vmax}' \cdot \tan\delta)/2$ = 8.3 kPa

Load = NSF x surface area

Load = NSF x π x External diameter x total height

Load = **518.3** kN

(g) Loading of waste, cap, restoration soils and gravel only

Load = (height x γ_{waste}) + (thickness x γ_{cap}) + (thickness x γ_{rest}) + (thickness x γ_{gravel})

Load = 216.0 kPa

Calculations:

Summary of loadings

Element	Extraction point	
Concrete chamber self weight	**135.7**	kN
Concrete slab	**64.8**	kN
Waste on slab	**1,287.9**	kN
Gravel on slab	**144.9**	kN
Cap and Restoration soils on slab	**305.9**	kN
Negative skin friction	**518.3**	kN
Total load	**2,457.5**	kN
Expressed as a pressure	**273.1**	kPa

2. Bearing capacity

(i) Total stress

The bearing capacity (q_f) of the clay liner beneath the square slab in total stress terms can be expressed as:

$q_f = c_u N_c + \sigma_v = c_u N_c + \gamma D$

where:

c_u is the undrained shear strength of the material within the bearing capacity failure zone

N_c is a bearing capacity factor = 6.2 obtained from page 6 (Skempton, 1951).

γD = (height x γ_{waste}) + (thickness x γ_{cap}) + (thickness x γ_{rest}) + (thickness x γ_{gravel})

γD = **216.0** kPa

For c_u = 50 kPa

q_f = **526.0** kPa

Factor of safety against shear failure is given by:

$F = q_f / q$

Factor of safety: **1.9**

Calculations:

(ii) Effective stress

The bearing capacity (qf) of the clay liner beneath the square slab in effective stress terms can be expressed as:

$q_f = 0.5\gamma_{clay}BN_\gamma + 1.2cN_c + p_oN_q$

where:

γ_{clay} is the unit weight of the clay liner beneath the slab

B = width of slab

c = cohesion of the clay liner

p_o = effective stress of overburden soil at foundation level

Assuming the maximum leachate head will be 3m (conservative),

p_o = 216.0 - (3 *10) **186.0** kPa

N_γ, N_c and N_q are bearing capcity factors given by:

$N_q = \exp\{\pi\tan\phi\} \times \tan^2(45+\phi/2)$

$N_q = \exp\{\pi * \tan$ 22 $\} \times \tan^2(45 +$ 22 $/2)$

N_q = **7.82**

$N_\gamma = (N_q - 1) \times \tan(1.4\phi)$

$N_\gamma = (N_q - 1) \times \tan(1.4 \times$ 22 $)$

N_γ = **4.07**

$N_c = (N_q - 1)\cot\phi$

$N_c = (N_q - 1) / \tan$ 22

N_c = **16.88**

Hence, q_f = **1597.0** kPa

Factor of safety against shear failure is given by:

$F = q_f / q$

Factor of safety: **16.2**

Calculations:

3. Settlement

Using the Skempton-Bjerrum method for consolidation settlement:

$\rho_{consol} = m_v \times H \times \Delta p \times \mu$

where:

m_v = 0.1 m^2/MN

μ = 0.5

H = 1 m (thickness of clay liner)

The increase in vertical stress under the centre of the slab, Δp, can be obtained from Janbu *et al.* , 1956 (see page 7)

z/B = 0.3 / 3 = 0.1 hence from Page 7 $\Delta p/q$ = 0.99

(a) Settlement under extraction slab

Maximum value of q = 273.1 hence Δ_p = 273.1 * 0.99 = **270.3** kPa

ρ_{consol} = 0.1 0.5 x 270.3 x 1

ρ_{consol} = 13.5 mm

Total settlement is typically no greater than 1.5 x ρ_{consol}

ρ_{tot} = 1.5 x 13.5 = **20.3** mm

(b) Settlement under waste only

Maximum value of q = 216.0

ρ_{consol} = 0.1 x 0.5 x 216 x 1

ρ_{consol} = 10.8 mm

Total settlement is typically no greater than 1.5 x ρ_{consol}

ρ_{tot} = 1.5 x 10.8 = **16.2** mm

(c) Differential settlement:

Settlement beneath slab = 20.3

Settlement beneath waste = 16.2

Differential settlment = 20.3 - 16.2 = **4.1** mm

Conclusions:

Both bearing capacity and anticipated settlement are considered satisfactory.

The leach

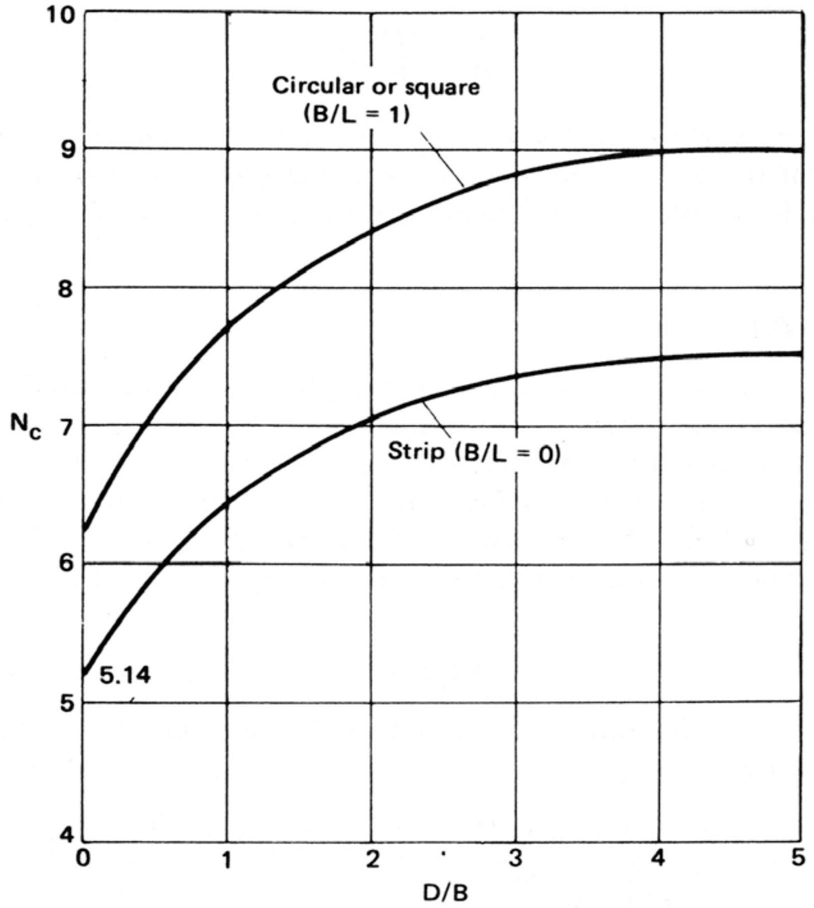


Fig. 8.5 Skempton's values of N_c for $\phi_u = 0$. (Reproduced from A.W. Skempton (1951) *Proceedings of the Building Research Congress*, Division 1, p. 181, by permission of the Building Research Establishment, © Crown copyright.)

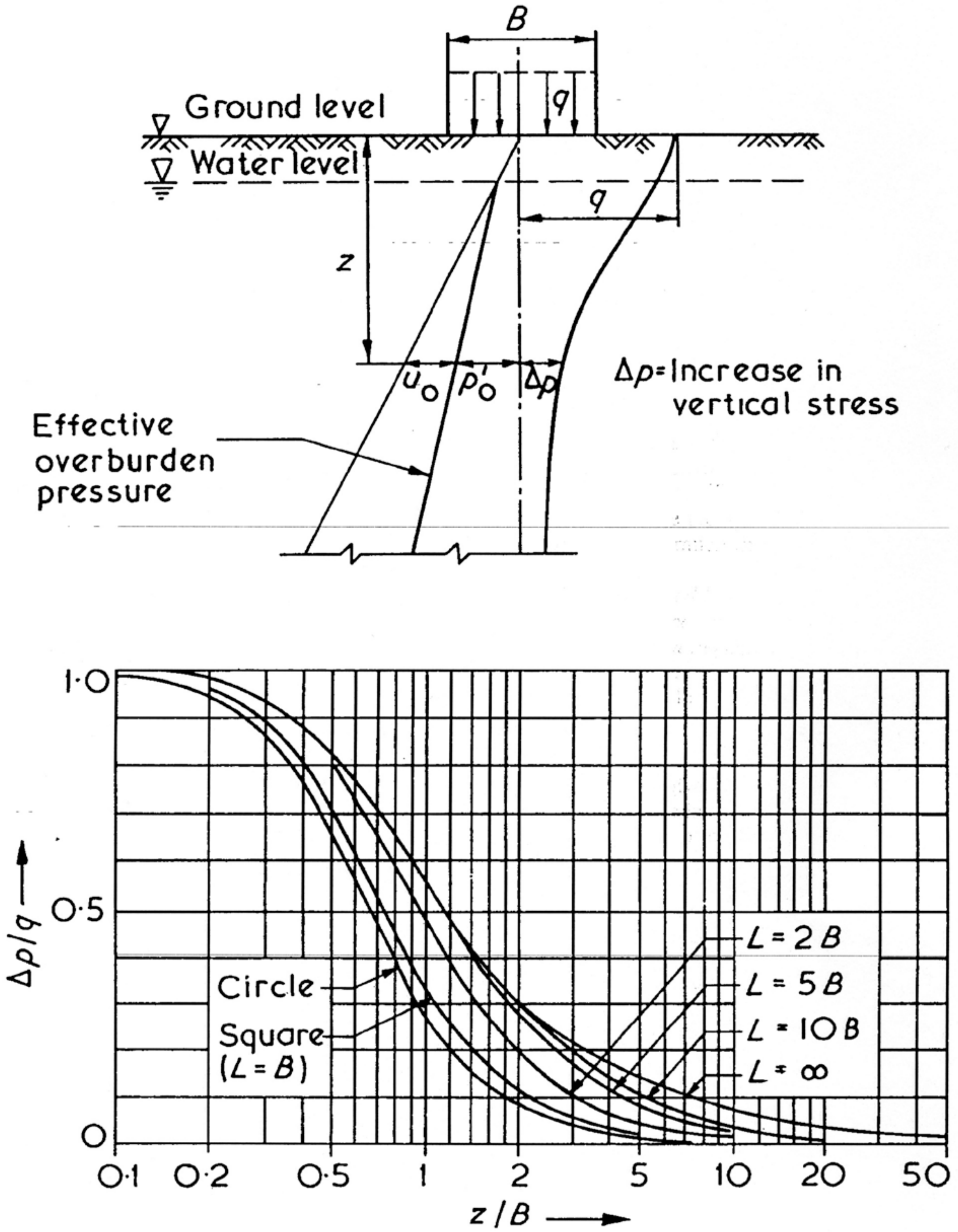


Fig. 3.3 Determination of increase in vertical stress under the centre of uniformly loaded flexible footings, after Janbu, Bjerrum and Kjaernsli (1956)

APPENDIX 501/6

Leachate Drainage Pipework Deflection Analyses

Leachate Pipework Strength Calculations

Aim: To assess strength of the leachate drainage pipe with a diameter of 180 mm.

Approach: To use the Iowa formula to predict the long term deformation of the leachate drainage pipe.

References:

1 Environment Agency, R&D Technical Report P1-397/TR, Landfill Engineering: Leachate Drainage, Collection and Extraction Systems, September 2002.

2 Qian X., Koerner R.M., and Gray D.H., Geotechnical Aspects of Landfill Design and Construction. Prentice Hall, 2002.

The Iowa Formulae can be used to predict the deformation of a pipeline at any stage in its life. The primary design limitation of long term deformation can be calculated using the following equation:

$$\delta_v = \frac{D_L\ K_X\ W_c}{(EI/r^3)+(0.061\ E')}$$ Equation 1.

Where:

W_c = Static Loading (simple prismatic loading is assumed)

= ((depth to crown of pipe·γ_{waste})+(leachate drainage thickness·γ_{gravel})+(clay/resto thickness·$\gamma_{restor\ soils}$))·OD of pipe

= ((17 m x 10 kN/m^3) + (0.45 m x 18 kN/m^3) + (2 m x 18 kN/m^3)) x 0.18

= **38.54** kN/m

D_L = Deflection lag factor (dimensionless)

= **1.5** (assumed)

K_x = Bedding factor

= **0.103** (value assumed is as recommended by the Water Research Centre)

r = Mean radius of pipe

= **90** mm

t = Wall thickness of pipe

= **16.36** mm

I = Moment of inertia of pipe wall per unit length

= **365.1** mm^3

E = Modulus of elasticity of the pipe material (long term)

= **150,000** kPa

S_L = (EI/r^3) = Long-term stiffness of pipe

= **75.1** kPa

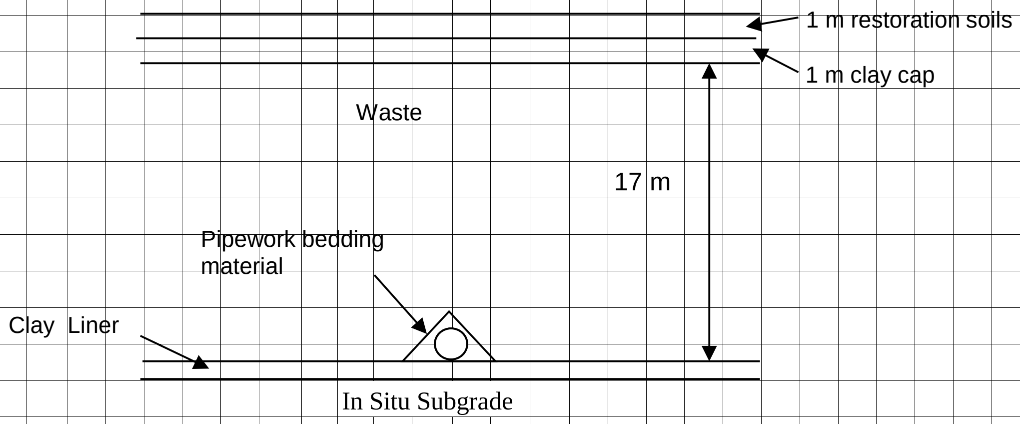
`

E' = Modulus of soil reaction

= **21,000** kPa, (corresponding to a crushed rock with little or no fines compacted to 85-95% Standard Proctor density Ref. 2 Table 7.9 reproduced on page 3)

PROJECT	**Park Grounds Landfill Stability Risk Assessment**				
Job No.	1894134	Made By:	BZ	Date:	28/06/2018
Ref.	Appendix 501/6	Checked:	DRVJ	Sheet:	2
		Reviewed:	DRVJ	of:	3

Geometry:



Calculation:

From Equation (1), the deflection of the pipe is given by:

δ_v = **0.004** m

= **4.39** mm

= **2.4** % of the nominal pipe inside diameter

The calculations indicate that once the waste has been placed, the leachate drainage pipe will deflect up to approximately 2.2%. It is envisaged that this amount of deflection will not result in intergrity failure of the pipe.

TABLE 7.9 U.S. BUREAU OF RECLAMATION VALUES OF MODULUS OF SOIL REACTION E' (kPa) FOR BURIED PIPELINES

Class ASTM D-2321	Soil type for pipe bedding material (Unified Classification System[A])	Dumped	Slight < 85% Std. Proctor[C] < 40% Rel. Den.[D]	Moderate 85–95% Std. Proctor 40–70% Rel. Den.	High > 95% Std. Proctor >70% Rel. Den.
I	Crushed rock: manufactured angular, granular material with little or no fines (6 to 38 mm)	7,000	21,000	21,000	21,000
II	Coarse-grained soils with little or no fines: GW, GP, SW, SP[B] containing less than 12 percent fines (max. particle size 38 mm)	NR	7,000	14,000	21,000
III	Coarse-grained soils with fines: GM, GC, SM, SC[B] containing more than 12 percent fines (max. particle size 38 mm)	NR	NR	7,000	14,000
IV(a)	Fine-grained soil (LL < 50): Soils with medium to no plasticity CL, ML, ML-CL, with more than 25 percent coarse-grained particles	NR	NR	7,000[E]	14,000[E]
IV(b)	Fine-grained soils (LL > 50): Soils with high plasticity CH, MH, CH-MH	NR	NR	NR	NR
	Fine-grained soils (LL < 50): Soils with medium to no plasticity CL, ML, ML-CL with less than 25 percent coarse-grained particles				

Organic soils OL, OM, and PT as well as soils containing frozen earth, debris, and large rocks are not recommended for initial backfill; NR = Not recommended for use per ASTM D-2321; LL = Liquid Limit.

[A]ASTM Designation D-2487

[B]Or any borderline soil beginning with some of these symbols (i.e., GM, GC, GC-SC).

[C]Percent Proctor based on laboratory maximum dry density from test standards using about 598,000 joules/m^3 (ASTM D-698)

[D]Relative Density per ASTM D-2049.

[E]Under some circumstances Class IV(a) soils are suitable as primary initial backfill. They are not suitable under heavy dead loads, dynamic loads, or beneath the water table. Compact with moisture content at optimum or slightly dry of optimum. Consult a Geotechnical Engineer before using.

Source: After Howard [14].

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