Stability Risk Assessment

Radlett SRFI Area 2

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Waterman Infrastructure & Environment Ltd
Pickfords Wharf, Clink Street, London SE1 9DG, United Kingdom
www.watermangroup.com

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Issue	Date	Prepared by	Checked by	Approved by
26-2-3	September 2023	Nathan Green Graduate Geotechnical Engineer	Yan Geng Associate Director	Freddie Alcock Technical Director

Comments

Disclaimer

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1. Introduction

1.1 The Brief

Waterman Infrastructure & Environment Limited ("Waterman") has been appointed to prepare an application for an Environmental Permit (EP). The EP application is to authorise the permanent deposit of waste on land as a recovery activity. The waste recovery activity is for site-derived waste to be used in the construction of landscape bunds associated with the construction of the Radlett Strategic Rail Freight Interchange (SFRI), located at North Orbital Road, Upper Colne Valley, Hertfordshire, AL2 2ET – specifically the two landscape bunds on Area 2.

SEGRO Radlett Ltd is the master developer – the party responsible for bringing the scheme to fruition. It has appointed VolkerFitzpatrick Limited (VFL) to undertake the earthworks including bund construction and other enabling activities. VFL is therefore the EP applicant and will be the EP operator.

A Slope Stability Risk Assessment report (SRA) is required to support the waste recovery EP application.

1.2 Context

Through the Radlett SRFI scheme SEGRO Radlett Ltd proposes to develop an intermodal terminal, with rail and road distribution units. The SRFI is located to the south of St. Albans, adjacent to the M25 and Midland Main line (MML) railway. The terminal will be serviced by a new dual track rail chord connected to the MML.

The SRFI comprises a 419-hectare (ha) development area that is sub-divided into eight plots referred to as Areas 1 to 8. The areas have the following proposed uses:

- Areas 1 (146 ha) and 2 (26 ha) – the SRFI Development Area. Area 1 will comprise an intermodal terminal and a rail and road served distribution facility consisting of several large warehouses. The rail chord connecting Area 1 to the MML will run through Area 2. Area 2 will also feature two landscape bunds (LS1 and LS2) that will help to screen the SRFI from public view and provide acoustic screening; and
- Area 3 to 8 (247 ha) – will be developed with additional works and landscaping to provide publicly accessible open land and a community forest.

The Areas are shown on plan "Different Development Phases (Areas 1 – 8) of the SRFI" (D-ESSD1A - drawings are to be found in the separate "ESSD drawings and information bundle").

To enable construction of the SRFI, earthworks are required to prepare the SRFI Development Area as summarised below:

Area 1

Earthworks material will be excavated from the northern half of Area 1 where the levels need to be lowered to enable access from the public highway to the north, to install surface water flow attenuation features and to create suitable development platform levels. The cut will be used to raise levels across the southern half of Area 1, to construct landscape bunds around the perimeter of Area 1 and to construct the landscape bunds on Area 2.

Area 2

Excavation is required in Area 2 to construct the new rail chord linking the MML and the SRFI – the rail chord needs to pass under the MML. Some of the excavation will be into historic landfill, with the waste arising to be processed by mobile treatment EP to generate useable earthworks material (i.e. meeting the specification for the works) with the unusable waste despatched for recovery or disposal elsewhere. The waste recovered from processing the historic landfilled waste as well as restoration soils and capping material from Area 2 and excavation arisings cut from Area 1 will be used to construct the landscape bunds on Area 2.

The cut and fill locations across Areas 1 and 2 are shown on plan “Earthworks Analysis Cut and Fill Volumes” (D-ESSD4A).

Regulatory Control of Earthworks

Pre-application liaison has been undertaken with both local (Hertfordshire and North London) and national (Permitting Support Centre) EA teams, seeking to establish the waste / non-waste status of various excavation arisings and the appropriate mechanisms to regulate the use of the arisings as earthworks materials. Aspects of this liaison are not concluded at the time of writing.

The southern part of Area 1 has been subject to mineral extraction and restoration. The land is recorded in Landmark data as “EA historic landfill polygon” and “LA recorded landfill site”. If the restoration material can be demonstrated to comprise overburden and interburden from the mineral extraction activity, excavation arising generated from that area will be excluded from the scope of waste. In that case, the reuse of such material will be managed under the Definition of Waste Development Industry Code of Practice (DoWCoP) in order to maintain an auditable record of the materials use within the earthworks. If the non-waste status of such material cannot be demonstrated / agreed, the arisings would be managed as waste. The local EA team has been provided with evidence to support non-landfill history of the southern part of Area 1 and the information has been passed forward to the EA team responsible for maintaining the historic landfill dataset with a request that the record is removed.

Natural soils and Made Ground will arise from excavation into the northern part of Area 1 – i.e. from land outside the historic mineral workings. Whilst natural soils excavated and able to be used in construction on the same site are excluded from the scope of waste, their use in earthworks on this scheme would be managed under the DoWCoP, as would the use of Made Ground.

The arisings from excavation into the historic landfill in Area 2 will be waste. The arisings will be treated under mobile treatment EP and the useful products of treatment will retain their waste label until their permanent deposit into earthworks, regulated by waste recovery EP. For the avoidance of doubt, the treatment will not be regulated by the site-based waste recovery EP.

Due to the unsettled status of the material to be cut from the mineral restoration area in Area 1, the waste recovery EP will include both bunds on Area 2. The permitted area boundary is limited to the areas occupied by landscape bunds LS1 and LS2 and is shown on plan “Area 2 Bunds Waste Recovery Area Boundary”) (D-ESSD1C). The boundary for Area 2 is shown on plan “Site Location Plan” (D-ESSD1B).

1.3 Report Structure and Scope

The EP application requires an SRA, which has been developed using the EA guidance.

The scope of the SRA includes:

- Review of available Ground Investigation (GI)
- Production of ground models and characteristic soil parameters for geotechnical analysis
- Slope stability assessments and ground movement analyses for characteristic sections though landscape bunds
- Maintenance and monitoring recommendations

1.4 Limitations and Constraints

Waterman has endeavoured to assess all information provided to them during the preparation of this document. But makes no guarantees or warranties as to the accuracy or completeness of this information.

The conclusions resulting from this report are not necessarily indicative of future conditions or operating practices at or adjacent to the site.

2. Conceptual Site Model

The stability conceptual site model is captured within the plans D-ESSD1A-D and D-ESSD4E, provided in the “ESSD drawings and information bundle” submitted with the EP application, the stability risk assessment in Section 3, and the data summary in Section 4.

3. Stability Risk Assessment

Likelihood		Severity				
		1 Minor	2 Moderate	3 Serious	4 Major	5 Catastrophic
1	Extremely unlikely	1	2	3	4	5
2	Unlikely	2	4	6	8	10
3	Likely	3	6	9	12	15
4	Extremely likely	4	8	12	16	20
5	Almost certain	5	10	15	20	25

Potential severity of harm occurring		
1	Minor	Minor damage or loss – (No human injury)
2	Moderate	Moderate damage or loss – (Slight injury or illness)
3	Serious	Substantial damage or loss – (Serious injury or illness)
4	Major	Major damage or loss – (Fatal injury or illness)
5	Catastrophic	Catastrophic damage or loss – (multiple fatalities)

Risk Classification	
Low (1 – 8)	Ensure assumed control measures are maintained and reviewed as necessary
Medium (9 – 19)	Additional control measures needed to reduce risk rating to a level that is equivalent to a test of ‘reasonably required’ for.
High (20 – 25)	Activity not permitted. Hazard to be avoided or risk to be reduced to tolerate level.

Risk ID	Hazard	Consequence	Likelihood	Severity	Risk	Mitigation	Likelihood	Severity	Residual Risk
1	Variable composition of Made Ground (General Fill) with low bearing capacity for slope stability.	Not adequate strength to support slopes in landscape bund and rail chord construction.	4	2	8	Embankment would require suitable placement and compaction of Engineered Fill, with minimum strength parameters to be calculated in slope stability/ground movement analysis.	1	3	3
2	Potential existence of soft Made Ground material on site.	Cause of excessive ground settlements or differential settlements to landscape bunds.	4	4	16	Necessary ground improvement (eg: excavate and replace) for the soft spots identified on site.	2	3	6
3	High groundwater table.	Flooding and accumulation of excessive pore water pressure, leading to instability/failure.	4	2	8	Porewater pressure monitoring during and post-construction. Review of flood risk assessment and drainage system, with implementation of groundwater controls if necessary.	2	2	4
4	Poorly backfilled/reinstated longitudinal service trenches and leaking pipework.	Water ingress into excavations causing instability/failure.	4	4	16	Ensure appropriate specification documentation provided to site personnel to emphasise the need to mitigate the risk. Works to be supervised by an appropriate qualified geotechnical professional.	1	4	4
5	Use of low strength material in construction of landscape bunds.	Instability/failure along the landscape bunds.	4	4	16	Ensure bund design specification is met during construction.	1	4	4
6	Presence of Landfill under landscape bunds.	Excessive settlement and differential settlement, potentially leading to instability.	4	4	16	Settlement monitoring and use of lighter fill material if required.	2	2	4

4. Data Summary

Data has been taken utilised from the Waterman Ground Conditions Report (RAD-WAT-A2EX-XX-RP-I-0003), provided as part of the EP application. Boreholes WBH103, WBH111, and WBH115 of the 2022 ground investigation are the most relevant to the present study.

4.1 Stratigraphy

The borehole logs indicate the presence of Topsoil, Made Ground – General Fill, Landfill Capping, Made Landfill, Basal Clay Layer, Kesgrave Catchment Subgroup, and Lewes Nodular Chalk and Seaford Chalk Formations. Where landfill was not encountered, the Made Ground – General Fill was directly underlain by the Kesgrave Catchment Subgroup.

Assumptions in relation to strata thickness and soil material description are presented in Table 1 for landfill areas and Table 2. For non-landfilled areas.

Table 1: Summary of encountered geological strata in landfilled areas

Strata	Thickness Range (Minimum – Max)	Description
Topsoil	0.1m – 0.4m	Grass over greyish brown/dark brown/brown slightly gravelly slightly sandy clayey silt with frequent rootlets, and occasional roots (up to 170mm diameter) and rare fragments (60x60mm) of textile. Gravel is subangular to rounded fine to coarse flint, brick, and rare concrete and chalk. Occasional pockets (up to 300mm) of stiff brown clay.
Made Ground – General Fill	0.1m – 1.85m	Soft brown/dark brown slightly gravelly slightly sandy clayey silt or slightly sandy gravelly silty clay with frequent roots (up to 250mm diameter) and rootlets. Gravel is angular to rounded fine to coarse flint, brick and concrete and rare chalk. Occasional fragments of plastic, textiles, glass, wood, and ceramic. Orangish brown/brown slightly gravelly clayey medium and coarse sand with occasional fragments of plastic. Gravel is angular to rounded fine to coarse flint and rare crystalline, chalk, brick and concrete.
Landfill Capping	0.1m – 2.5m	Stiff brown mottled greyish brown/orangish brown slightly sandy slightly gravelly silty clay. Gravel is subangular to rounded fine to coarse flint and rare brick, concrete, and chalk.
Landfill	0.2m – 5.7m	Domestic waste comprising glass, plastic, polystyrene, ceramic, metal, cables, textiles, paper, sponges, tin, newspaper (dated 1980), fragments of paper, cardboard, and book (1979) in a dark greyish brown and black sandy gravelly clay matrix. Construction-type waste including fragments of brick and masonry, concrete, and tarmacadam. Other fragments of wood, rubber, black and white plastic sheeting, electrical wires, ripped nylon sheet, wood chippings, rope, clumps of straw.

Strata	Thickness Range (Minimum – Max)	Description
Basal Clay Layer	0.25m – 3.0m	Soft to stiff orangish brown/brown slightly gravelly silty clay with rare fragments of wood and plastic. Gravel is subangular to rounded fine to coarse flint, chalk and rare brick. Soft to firm greenish brown and dark brown grey slightly gravelly sandy clay with rare pockets of firm orangish brown mottled bluish grey clay. Rare fragments of metal, plastic, and wood. Gravel is angular to rounded fine to coarse flint and brick.
Kesgrave Catchment Subgroup	0.8m – 9.0m	Firm to stiff orangish brown and dark brown slightly gravelly sandy clay with rare pockets (up to 80x100m) of firm orangish brown mottled bluish grey clay. Gravel is angular to rounded fine to coarse flint.
	0.6m – 4.6m	Overlying very dense brown, light brown and greenish brown slightly clayey sandy angular to rounded fine to coarse flint gravel.
Chalk	0.85m – 12.1m	Structureless white mottled light grey/yellow white slightly sandy slightly gravelly silt or silty sandy gravel with a low subangular and subrounded flint and cobble content. Gravel is angular to subrounded fine to coarse weak chalk and flint (CIRIA Grade Dc and Dm).
	>11.95m (total thickness not proven)	Becoming extremely to very weak medium locally high density white mottled grey with rare black specs chalk rarely stained orangish brown. Rare bivalve shell fragments. Frequent rounded dark grey/black cobble sized flints recovered between 0.05m and 0.5m thick (CIRIA Grade A3/B3).

Table 2: Summary of encountered geological strata in non-landfilled areas

Strata	Typical Thickness (Minimum – Max)	Description
Topsoil	0.05m – 0.6m	Grass over greyish brown/dark brown/brown slightly gravelly sandy silt with frequent rootlets and occasional roots (up to 600mm diameter). Gravel is angular to rounded fine and medium flint, brick and rare glass, chalk, and concrete.
Made Ground – General Fill	0.2m – 2.95m	Silty very sandy gravel or slightly gravelly sandy silt with fragments of fine to coarse clinker, brick, flint, concrete and rare tarmacadam, coal, ash, ceramic, and glass gravel. Occasional medium subangular brick cobble content, roots (up to 90mm diameter) and rootlets. Firm to stiff sandy gravelly clay or clayey sandy gravel. Gravel is subangular to subrounded fine to coarse flint, brick, and chalk. Occasional fragments of clinker, plastic, and concrete.
Kesgrave Catchment Subgroup	3.0m – 8.2m	Firm becoming stiff orangish brown mottled light grey/dark grey, slightly sandy slightly gravelly clay. Gravel is angular to rounded fine to coarse flint and rare chalk. Occasional thin horizons (>0.5m thick) of reddish brown locally mottled grey slightly gravelly sandy clay with frequent black

Strata	Typical Thickness (Minimum – Max)	Description
		staining and rare remnant rootlets. Gravel is angular to rounded fine to coarse flint. Orangish brown very clayey very sandy angular to rounded fine to coarse flint gravel.
	1.8m – 13.8m	Loose to very dense yellowish brown slightly gravelly fine and medium sand. Gravel is angular to rounded fine and medium flint and quartz. Becoming medium to very dense yellowish brown sandy subangular to rounded flint gravel with a low subrounded flint cobble content.
Chalk	0.9m – 10.3m	Interbedded very soft to soft off white/brown white/yellow white slightly sandy gravelly silt and silty sandy gravel with a low subangular and subrounded flint and chalk cobble content. Gravel is angular to subrounded fine to coarse weak chalk and flint (CIRIA Grade Dc and Dm).
	>16.05m (total thickness not proven)	Becoming extremely weak medium density white with rare black specs chalk rarely stained orangish brown. Rare bivalve shell fragments. Frequent rinded dark grey/black cobble sized flints recovered between 0.05m and 0.3m thick (predominantly CIRIA Grade B4/B3).

4.2 Ground Models and Geotechnical Parameters

The ground models and soil parameters have been based upon information provided in the Waterman Ground Conditions Report and Landscape Bunds: Geotechnical Design Report (GDR - RAD-WAT-A2EX-XX-RP-C-016) (included with the EP application). For the analysis undertaken in this report, three different sections will be considered. Given the variable stratigraphy across Area 2, three separate ground models have been applied for each section analysed. These consider WBH103 for the northern bund section, WBH111 for the tallest bund section, and WBH115 for the thickest underlying Landfill section.

The ground model and characteristic material parameters summarised in Tables 3 - 5 will be used in the geotechnical design.

Table 3: WBH103 Ground Model and geotechnical parameters.

Strata	Elevation at Top of Stratum	Bulk Unit Weight	Undrained Shear Strength	Drained Shear Strength		K_0	Young's Modulus (undrained)	Young's Modulus (Drained)
	(mAOD)	γ_b (kN/m3)	c_u (kN/m^2)	c' (kN/m^2)	φ°		Eu (MN/m^2)	E' (MN/m^2)
Made Ground	+71.5	18.0	80	0.0	29	0.52	32.0	25.6
Landfill	+70.8	17.0	40.5	0.5	24	0.59	16.2	13.0
Clay	+68.2	18.0	49.5	1.0	26	0.56	19.8	15.8
Kesgrave Catchment Subgroup	+63.3	17.0	-	0.0	34	0.44	-	50

Strata	Elevation at Top of Stratum	Bulk Unit Weight	Undrained Shear Strength	Drained Shear Strength		K_0	Young's Modulus (undrained)	Young's Modulus (Drained)
	(mAOD)	γ_b (kN/m3)	c_u (kN/m^2)	c' (kN/m^2)	φ°		Eu (MN/m^2)	E' (MN/m^2)
Lewes Nodular Chalk Formation and Seaford Chalk Formation	+59.9	20.0	207+18.2z	5.0	30	0.50	82.8+7.3	66.2+5.8z

Table 4: WBH111 Ground Model and geotechnical parameters.

Strata	Elevation at Top of Stratum	Bulk Unit Weight	Undrained Shear Strength	Drained Shear Strength		K_0	Young's Modulus (undrained)	Young's Modulus (Drained)
	(mAOD)	γ_b (kN/m3)	c_u (kN/m^2)	c' (kN/m^2)	φ°		Eu (MN/m^2)	E' (MN/m^2)
Made Ground – granular	+70.5	18.0	67.5	0.0	29	0.52	27.0	21.6
Clay	+68.7	18.0	49.5	1.0	26	0.56	19.8	15.8
Kesgrave Catchment Subgroup	+65.5	17.0	-	0.0		0.44	-	40
Lewes Nodular Chalk Formation and Seaford Chalk Formation	+62.8	20.0	94.5+11.1z	5.0	30	0.50	7.2+6.7z	30.3+3.6z

Table 5: WBH115 Ground Model and geotechnical parameters.

	Elevation at Top of Stratum	Bulk Unit Weight	Undrained Shear Strength	Drained Shear Strength		K_0	Young's Modulus (undrained)	Young's Modulus (Drained)
	(mAOD)	γ_b (kN/m3)	c_u (kN/m^2)	c' (kN/m^2)	φ°		Eu (MN/m^2)	E' (MN/m^2)
Made Ground – granular	+71.5	18.0	54.0	0.0	29	0.52	21.6	17.3
Landfill	67.8	17.0	45.0	0.5	24	0.59	18.0	14.4
Lewes Nodular Chalk Formation and Seaford Chalk Formation	+61.5	20.0	121.5+17.5z	5.0	30	0.50	48.6+7.0z	38.9+5.6z

Notes

- z refers to depth below top of the Lewes Nodular Chalk Formation and Seaford Chalk Formation.
- The short-term total stress (undrained) stiffness for cohesive strata has been obtained by correlation with the undrained shear strength data for the anticipated range of strain in the respective analytical models. The long-term effective stress (drained) stiffness for cohesive strata has been taken as 80% of the total stress (undrained)

stiffness, following principles of elasticity theory (assuming a Poisson's Ratio of 0.2).

- Angle of shearing resistance for granular soils has been based on the correlation $\varphi=30°+A+B+C$ (BS 8002:2015), where A depends on the particles angularity, B depends on the grading and C depends on the SPT results or an SPT correlation based on Peck et. Al 1974 suggested relationship.
- Cohesive stiffness profiles indicated are based on the relationship EU=400CU for foundations. The use of this correlation is considered conservative in view of the general nature of the soil-structure interaction analysis and the strain levels expected to develop in the proximity of various geotechnical works.
- Stiffness estimation for granular soils has been based on the correlation E'=1*SPT N (Mpa).
- Groundwater assumed at 0m below ground level (bgl), (the highest water level recorded in the GI was approximately 1.0m bgl, setting water level at 0.0m bgl allows for a level of conservatism in the model).
- Landfill waste is not a standard geotechnical material. The above parameters have been interpreted from laboratory test results. Given the nonstandard, extremely heterogeneous nature of landfill waste, caution shall be exercised when using these parameters. Extensive and robust sensitivity checks of the landfill waste properties is required for detailed design as well as applying appropriate factors of safety.

The bund material will be modelled using both cohesive and granular fill to represent the use of Class 1, 2 and 3 materials. The minimum strength parameters provided in the GDR have been adopted in this analysis. These are provided in Table 6.

Table 6: Fill material geotechnical parameters.

Fill Type	Bulk Unit Weight	Undrained Shear Strength	Drained Shear Strength		Young's Modulus
	γ_b (kN/m3)	c_u (kN/m^2)	c' (kN/m^2)	φ°	E (MN/m^2)
Granular	19	-	0.5	25	20
Cohesive	19	50	-	-	20

Notes

- Negligible cohesion (c') applied to granular strength to resolve numerical issues in shallow areas.

4.3 Groundwater

Groundwater monitoring conducted within Area 2 recorded shallow pockets of perched water recorded in the landfill between 2.93mbgl and 5.98mbgl (67.51mAOD and 64.46mAOD, respectively). Typically, no groundwater was recorded in boreholes targeting the landfill waste (except for BH58(S)) during the 2022 Waterman ground investigation. In BH58(S) groundwater was recorded at 4.66 and 3.77mbgl (74.7mAOD and 70.93mAOD, respectively) in two of the three return monitoring visits. The groundwater level recorded in the landfill is higher than groundwater levels in the Kesgrave Gravels or Chalk Formation suggesting connectivity between water in the landfill and groundwater is restricted. This aligns with the fact that a clay 'basal' layer (either purposely placed or natural clay occurring in the Kesgrave Deposits) is present directly underlying much of the landfill waste.

For the purpose of geotechnical design, a conservative groundwater level of 2.9mblg will be considered.

A detailed description of groundwater levels is provided in the Waterman Ground Conditions report.

5. Modelling Approach and Software Justification

5.1 General

Numerous settlement and slope stability checks have been undertaken to determine the stability of the bunds in areas of cut and fill in Area 2. Three sections have been chosen for analysis, with their location and reasoning behind their choice laid out as follows:

- Section A-A' – Worst-case section in terms of height and thickness of underlying landfill for the northern bund, which runs in close proximity to the proposed rail chord.
- Section B-B' – Worst-case section in terms of bund height across both bunds, located centrally along the southern bund.
- Section **C-C' –** Worst-case section in terms of thickness of underlying landfill, located towards the south end of the southern bund.

This analysis has been completed using Plaxis 2D 2022 software, in which a 2D finite element (FE) soil-structure interaction plane strain analysis has been carried out in order to evaluate the ground movements induced by construction stages and proposed loadings.

Soil layers have been modelled using linear elastic perfectly plastic (Mohr-Coulomb failure criterion) constitutive model. The short-term (S-T) undrained behaviour of has been modelled with effective properties stiffness and undrained shear strength. Long-term (L-T) conditions are achieved by performing a final consolidation analysis in which all excess pore water pressures generated during the previous construction stages are dissipated and ground water equilibrium is achieved. Soil stratigraphy and geotechnical parameters have been taken from Tables 3 - 5. Undrained behaviour has been assumed for all strata, excluding the Made Ground and Kesgrave Catchment Subgroup, during short term loading/unloading stages. The long-term behaviour of the cohesive strata is modelled by introducing drained condition properties to the soil layers.

The sections chosen for analysis are shown in Figure 1, with the full drawing of Area 2 bund plan and sections provided in D-ESSD1C. Section A-A' is a typical section through the northern bund, section B-B' represents the tallest section of the southern bund, and section C-C' encompasses the area of thickest landfill, as shown in WBH115 with 6.3m landfill thickness. Characteristic cross sections are given in Figure 2, with the aforementioned section lines being representative of chainage 120m, 600m and 800m, respectively.

A sensitivity check has been undertaken on section C-C', to assess the effect of reducing the bund strength parameters on the maximum settlement of the bund.

The construction of the bunds has been modelled in 1m layers, from existing ground level up to 80m AOD, with consolidation following construction of each layer.

Figure 1: Plan view of Area 2 and locations of sections used in analysis

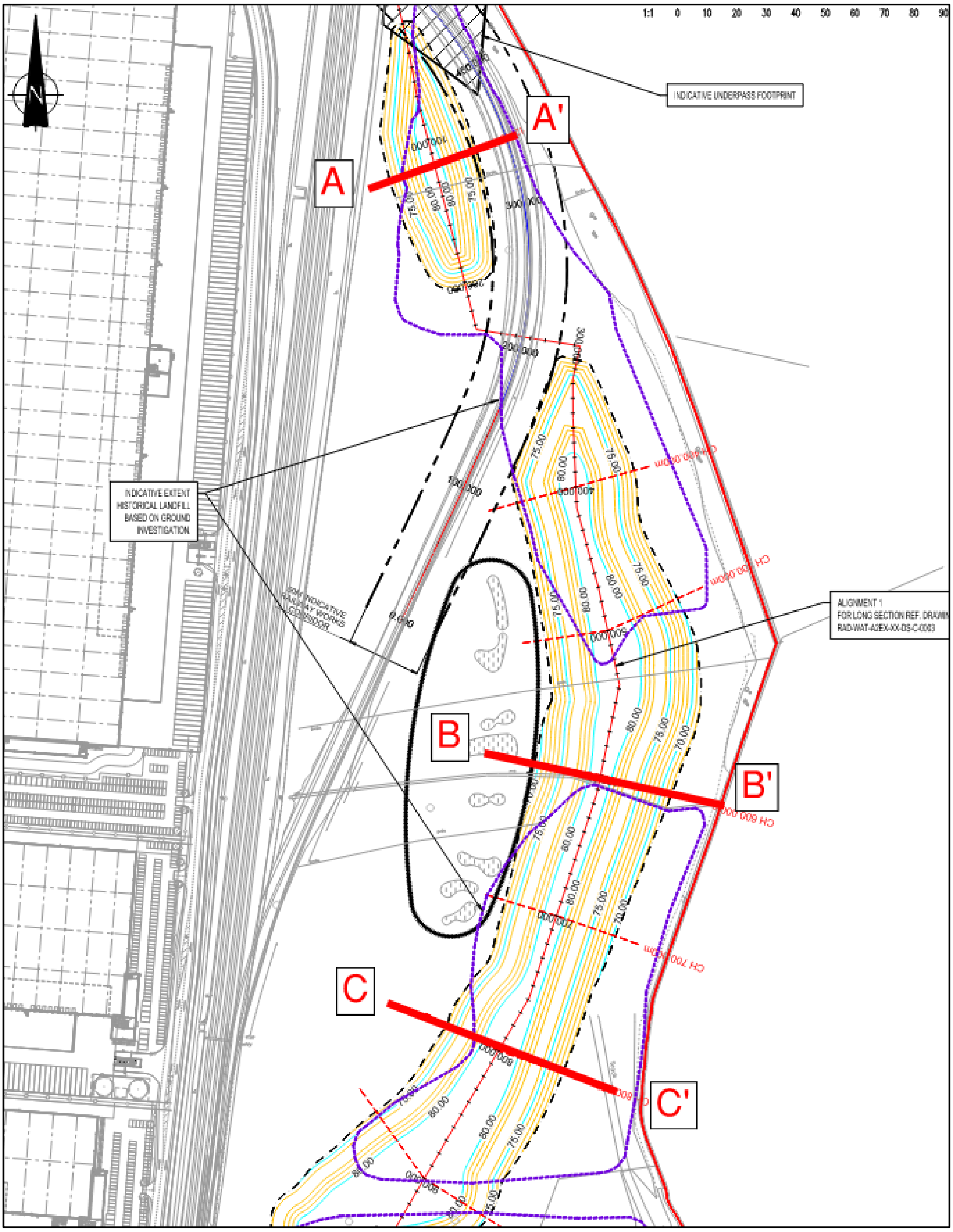
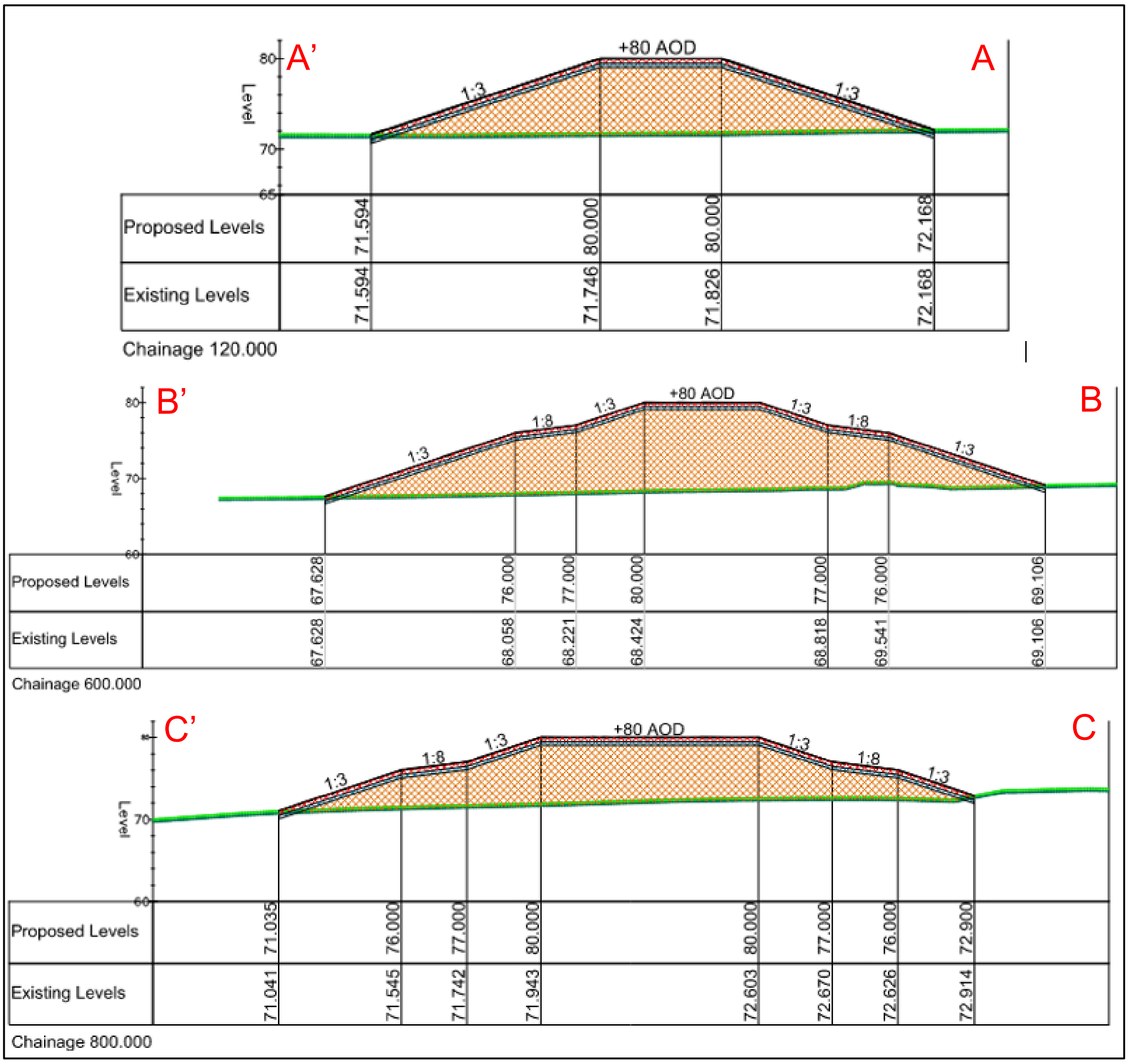


Figure 2: Cross sections to be modelled in analysis



5.2 Loadings

The bund has no operational function, but as a worst-case scenario, a 10 kN/m line load will be applied to the top of the bund. An assumed line load of 20kN/m will be applied to the rail chord for the relevant section.

5.3 Construction Sequence

The following models follow the same construction sequence, which are as follows:

- **Initial phase** – K0 procedure with existing conditions;
- **Rail chord temporary works (Section A-A' only)** – Construction of rail chord using assumed temporary works;
- **Bund construction phase** – construction of bund in 1m layers with consolidation to minimum excess pore water pressure following deposition of each layer;
- **Loading phase** – All relevant line loads activated;

- **Short-term Factor of Safety (FoS)** – Short-term slope stability analysis;
- **Long-term conditions** – Consolidation to minimum excess pore water pressures and switching to drained properties for cohesive strata; and
- **Long-term FoS –** Long-term slope stability analysis.

6. Factors of Safety

This assessment will obtain a Factor of Safety (FoS) value, which will be applied to the Eurocode 7 design requirement of FoS>1.25. FoS results with a value greater than 1.25 are considered stable and satisfy the EC7 requirement, while values of less than 1 indicate risk of immediate failure. The cases with values between 1 and 1.25 are considered stable, but do not meet the EC7 design requirement.

The geotechnical design is based on BS EN 1997-1 (EC7) : 2004 Design Approach 1 Combination 2 (DA1C2; governing approach for slope stability checks), where partial factors are applied to ground strength and actions. Table 7 and Table 8 below set out the partial factors considered. DA1C2 considers M2 and A2 factors.

Table 7: EC7 Design Approach 1, Partial Factors applied for Soil Parameters.

Soil Parameter (M)	Symbol	Set	
		M1	M2
Angle of Shearing Resistance	$\gamma_{\phi'}$	1.0	1.25
Effective Cohesion	$\gamma_{C'}$	1.0	1.25
Undrained Shear Strength	γ_{Cu}	1.0	1.4
Weight Density	γ_{γ}	1.0	1.0

Table 8: EC7 Design Approach 1, Partial Factors applied for Actions (destabilising forces only).

Actions (A)	Symbol	Set	
		A1	A2
Self-Weight of Soil	W	1.35	1.0
Permanent Surcharge	q_p	1.35	1.0
Variable Surcharge	q_v	1.5	1.3

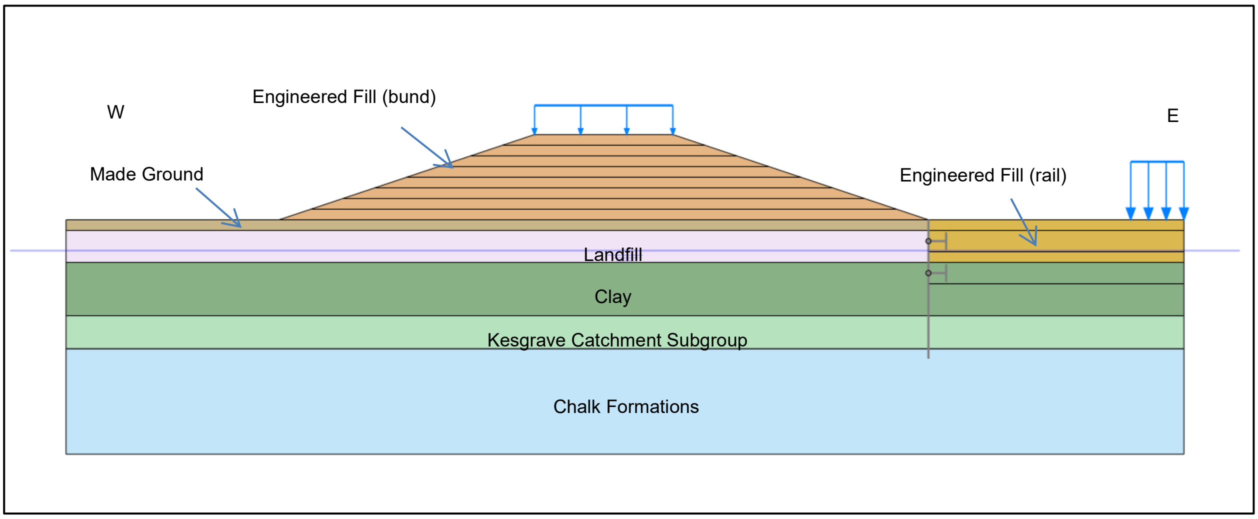
7. Assessment

7.1 Section A-A’

Section A-A’ comprises the bund with a maximum height of 8.5m and continuous 1 in 3 slopes from the crest to the toe on both sides at existing ground level. This section adopts the WBH103 ground model provided in Table 3. In this section, the bund exists in close proximity to the 50m indicative rail corridor, which will require excavation of landfill and replacement with engineered fill down to Clay. The outline of the corridor is provided in plan D-ESSD4E. The design of the temporary works is outside Waterman’s scope and has therefore been assumed.

A view of the Plaxis 2D model can be seen in Figure 3.

Figure 3: View of Plaxis 2D model - Section A-A'



When modelling using granular fill, the maximum total settlement experienced was 235mm in the long-term stage, as shown in Figure 4. The FoS analysis calculated a FoS>1.25 for both short and long-term conditions, with the long-term failure mechanism being highlighted in (Figure 5)

Figure 4: Total vertical displacement, Section A-A' Granular - long-term stage

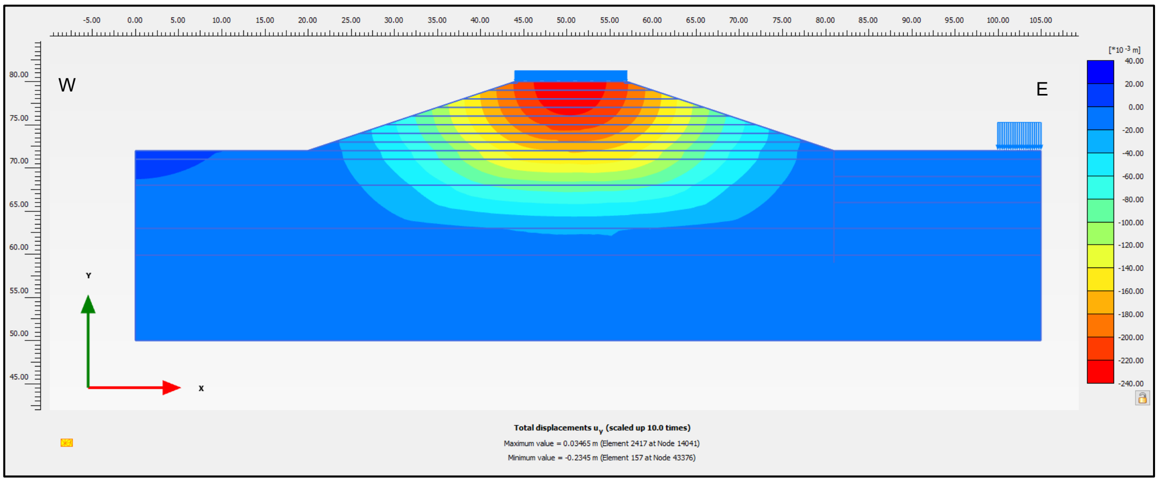
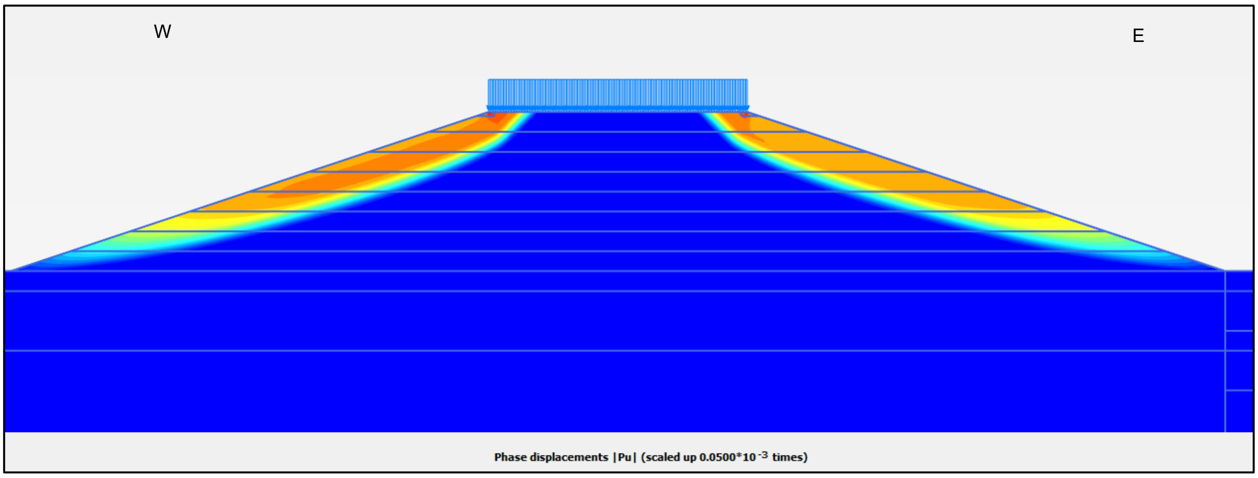


Figure 5: FoS analysis, Section A-A' Granular - long-term stage



While using cohesive fill, the maximum total settlement experienced was 210mm in the long-term stage, as shown in Figure 6, with results for the model summarised in Table 9. The FoS analysis at this stage calculated FoS>1.25, and highlights the potential failure pattern on both slopes (Figure 7).

Figure 6: Total vertical displacements for Section A-A' Cohesive - long-term stage

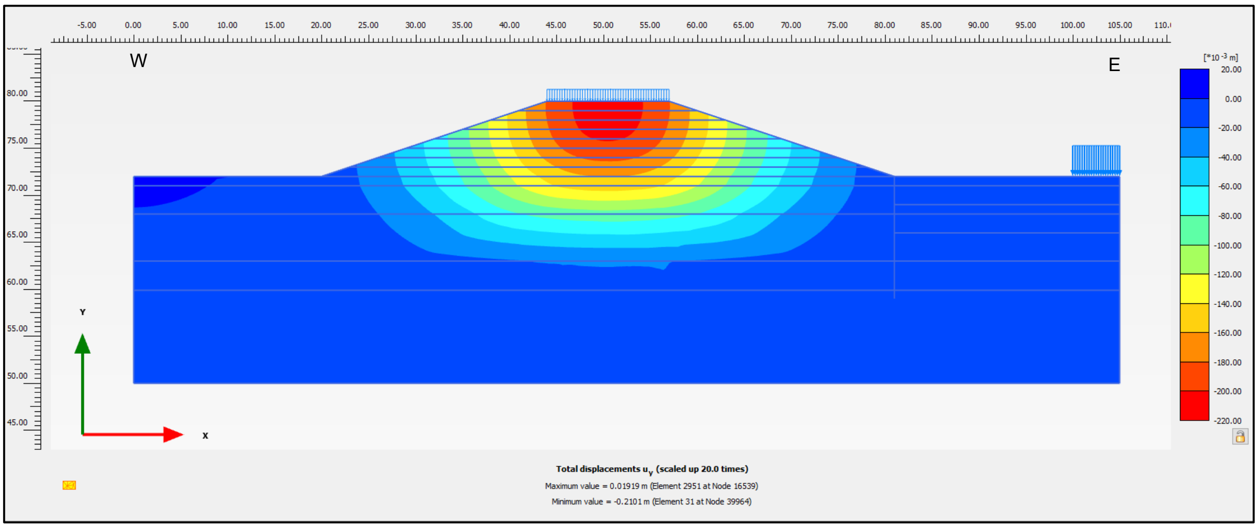


Figure 7: FoS analysis for Section A-A' Cohesive – long-term stage

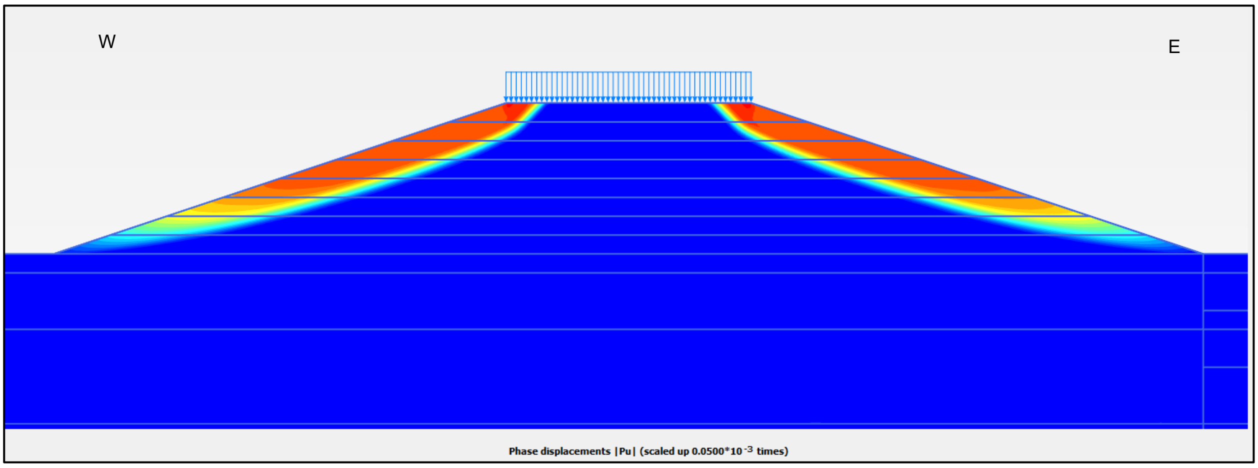


Table 9: Summary of results – Section A-A’

Model	S-T Max Settlement (mm)	L-T Max Settlement (mm)	S-T FoS	L-T FoS
A-A’ Granular	219	235	>1.25	>1.25
A-A’ Cohesive	180	210	>1.25	>1.25

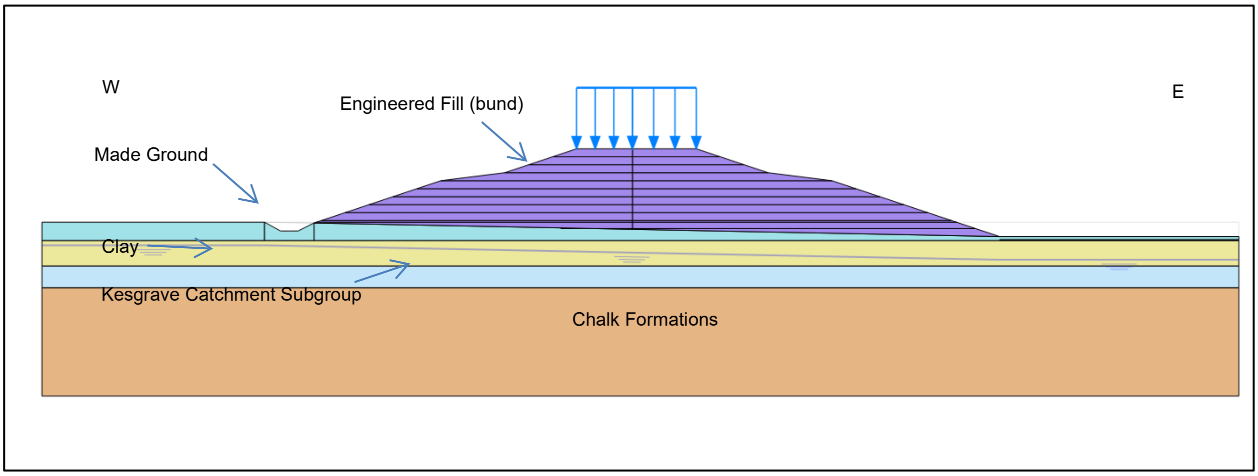
The area and works required in construction of the rail chord embankment are still to be confirmed. If these vary significantly from what has been modelled, then this section must be updated.

7.2 Section B-B’

Section B-B’ has been selected due to it having the maximum bund height, at 11.78m. This section adopts the WBH111 ground model (Table 4), which is without underlying landfill. At this location, the bund consists of 1 in 3 slopes, separated by intermediate 1 in 8 berms. This section also considers the 1 in 2 sloped swale, which is positioned directly at the toe of the bunds western slope.

A view of the Plaxis 2D model is shown in Figure 8.

Figure 8: View of Plaxis 2D model – Section B-B'



For the case of granular fill, as shown in Figure 9, maximum predicted total settlement is 392mm at the long-term stage. The FoS analysis calculated a FoS>1.25 for both short and long-term conditions, with the potential failure mechanism being highlighted in Figure 10.

Figure 9: Total vertical displacements for Section B-B' Granular - long-term stage

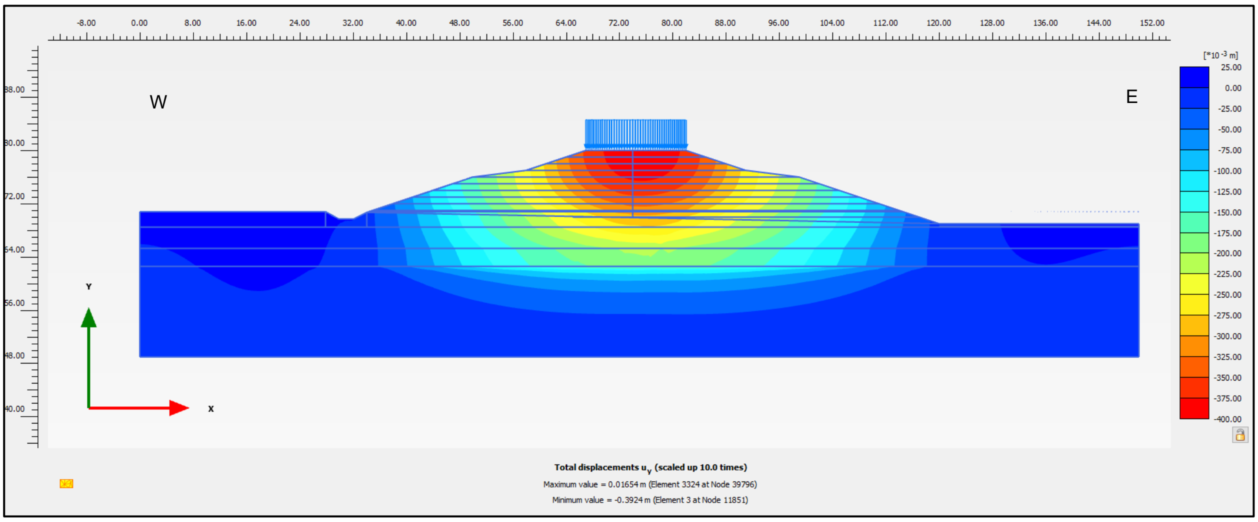
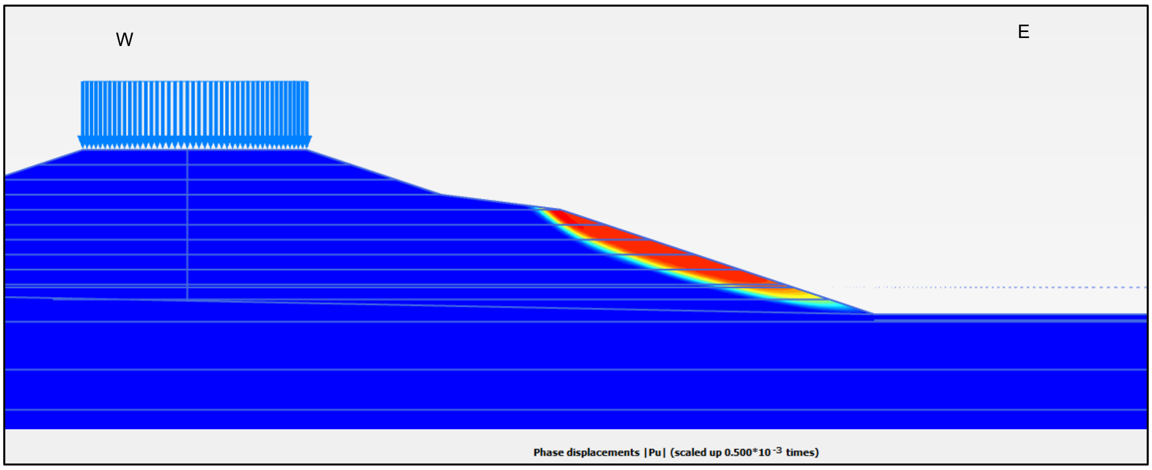


Figure 10: FoS analysis for Section B-B' Granular - long-term stage



For the case of cohesive fill, as shown in Figure 11, maximum predicted total settlement is 395mm at the long-term stage, with results of the analysis summarised in Table 10. The FoS analysis calculated FoS>1.25 for both short and long-term conditions. The potential failure mechanism is highlighted in Figure 12.

Figure 11: Total vertical displacements for Section B-B' Cohesive - long-term stage

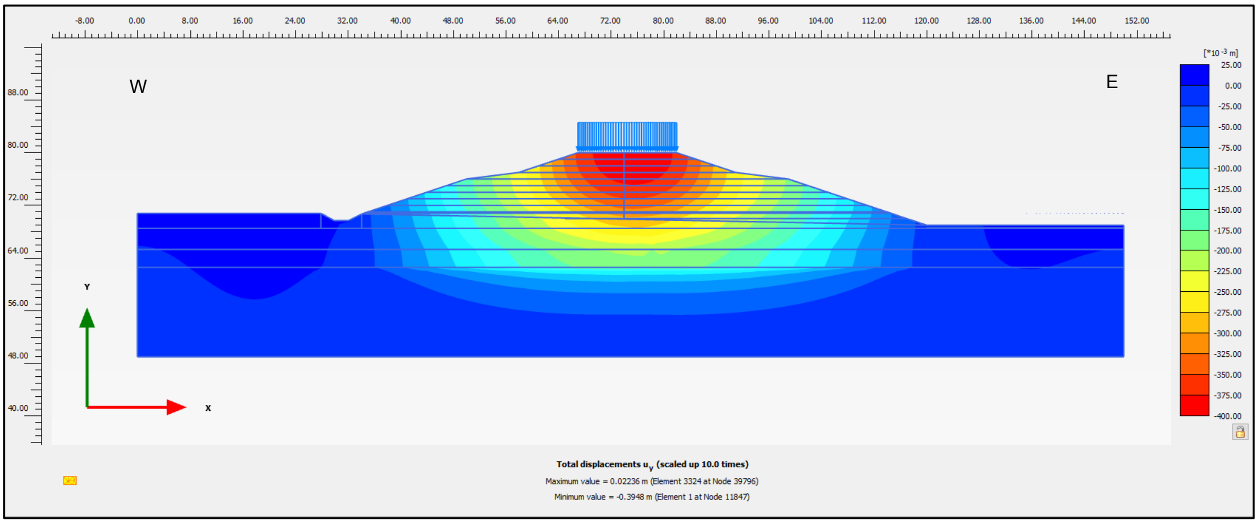


Figure 12: FoS analysis for Section B-B' Cohesive - long-term stage

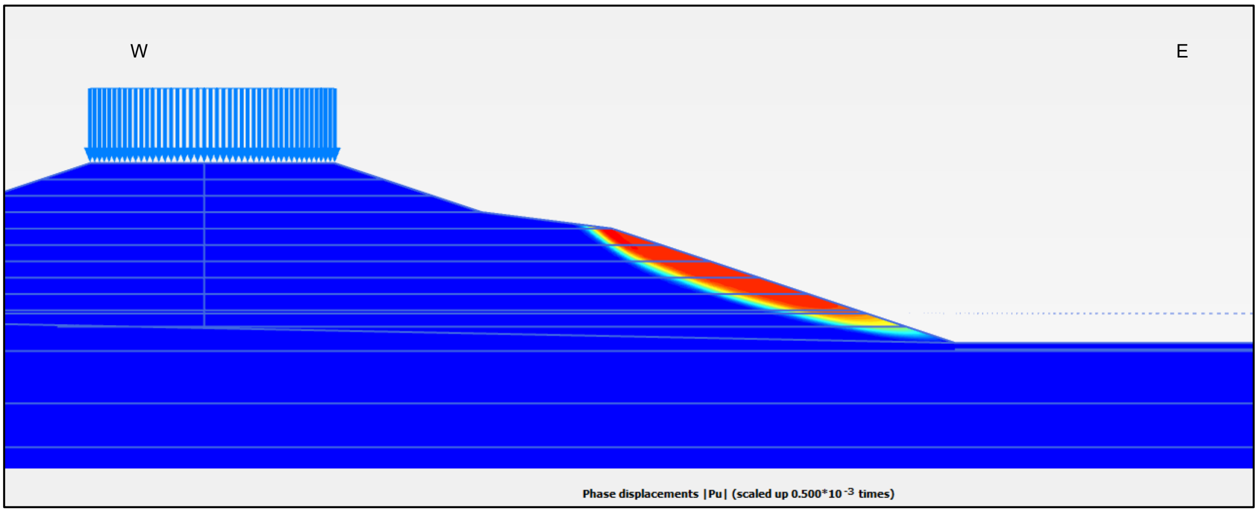


Table 10: Summary of results – Section B-B'.

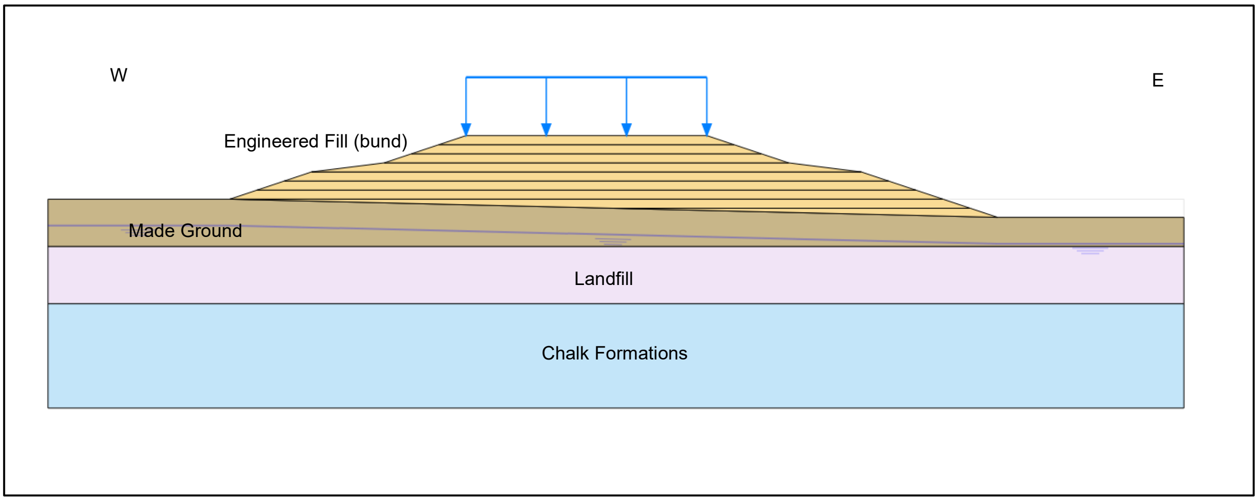
Model	S-T Max Settlement (mm)	L-T Max Settlement (mm)	S-T FoS	L-T FoS
B-B' Granular	384	392	>1.25	>1.25
B-B' Cohesive	361	395	>1.25	>1.25

7.3 Section C-C'

Section C-C' is representative of the thickest layer of underlying landfill. This section adopts the WBH115 ground model, presented in Table 5. It has the same slope design as Section B – B', but with a lower maximum height of circa 9.0m.

A view of the Plaxis 2D model is shown in Figure 13.

Figure 13: View of Plaxis 2D model – Section C-C'



Using granular fill, the maximum total settlement was 241mm during the long-term stage, as displayed in Figure 14. The FoS analysis calculated FoS>1.25, and highlights the potential failure mechanism on the eastern slope (Figure 15).

Figure 14: Total vertical displacements for Section B-B' Granular - long-term stage

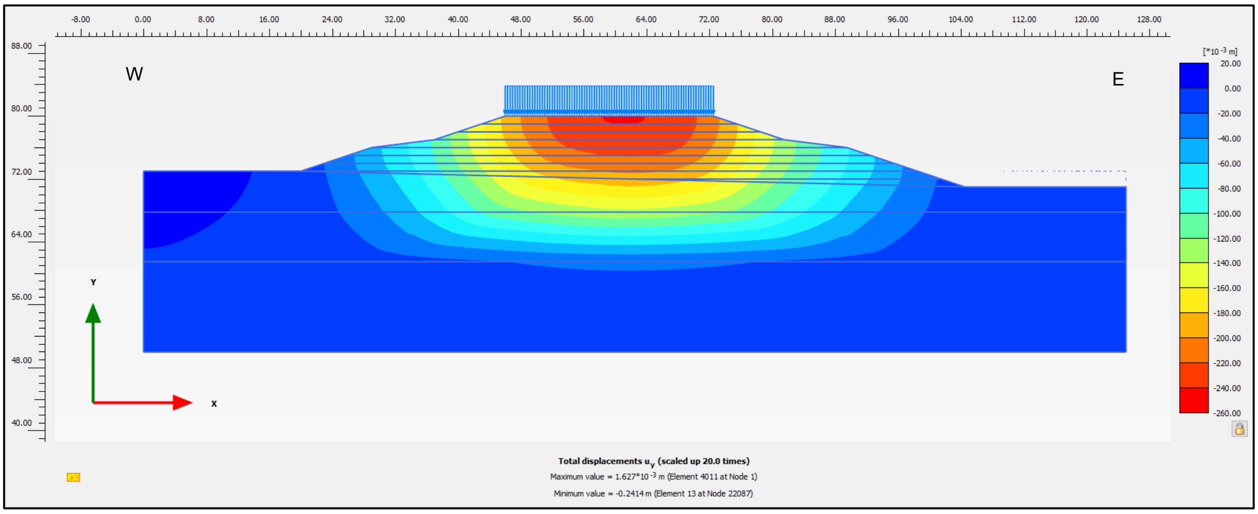
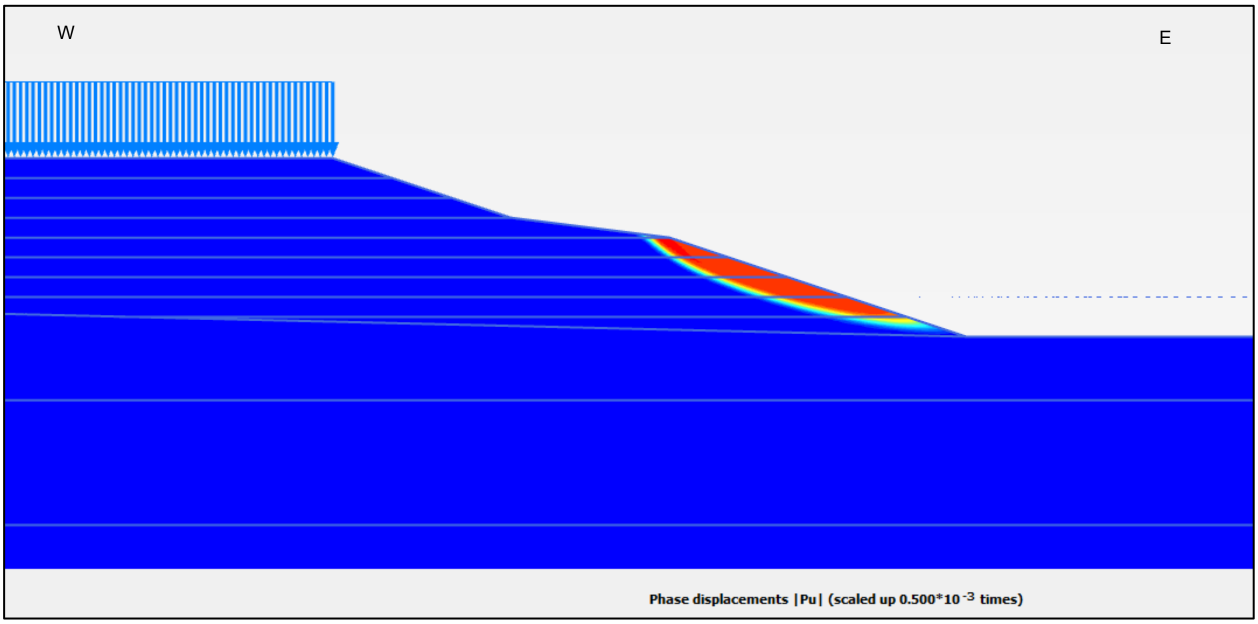


Figure 15: FoS analysis for Section C-C' Granular - long-term stage



Using cohesive fill, the maximum total settlement was 234mm, during the long-term stag, as shown in Figure 16. The FoS analysis calculated FoS>1.25 for both short and long-term conditions, with the long-term failure mechanism highlighted in Figure 17.

Figure 16: Total vertical displacements for Section B-B’ Cohesive - long-term stage

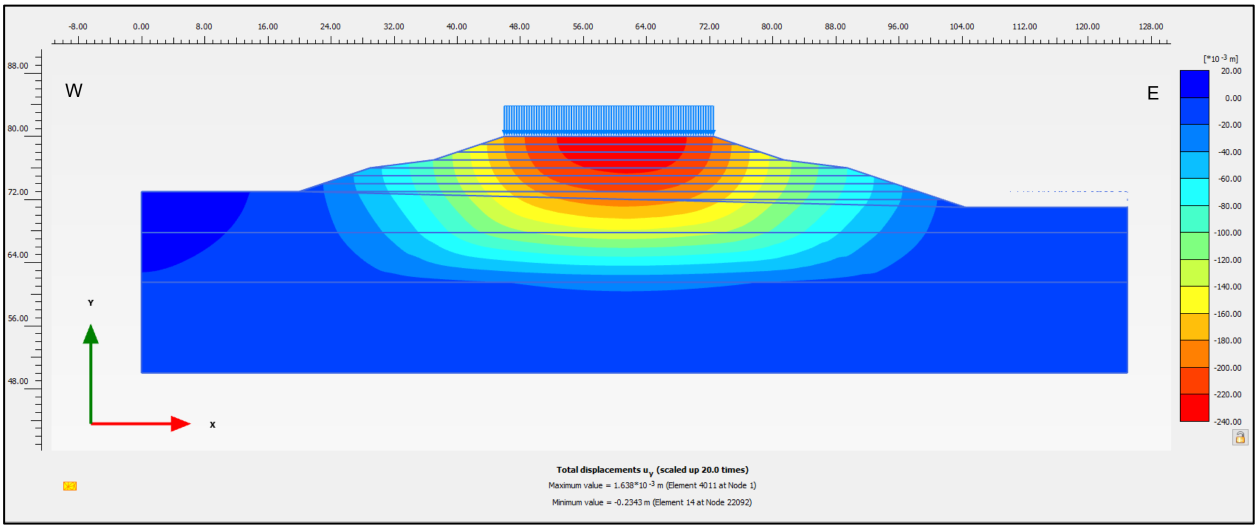
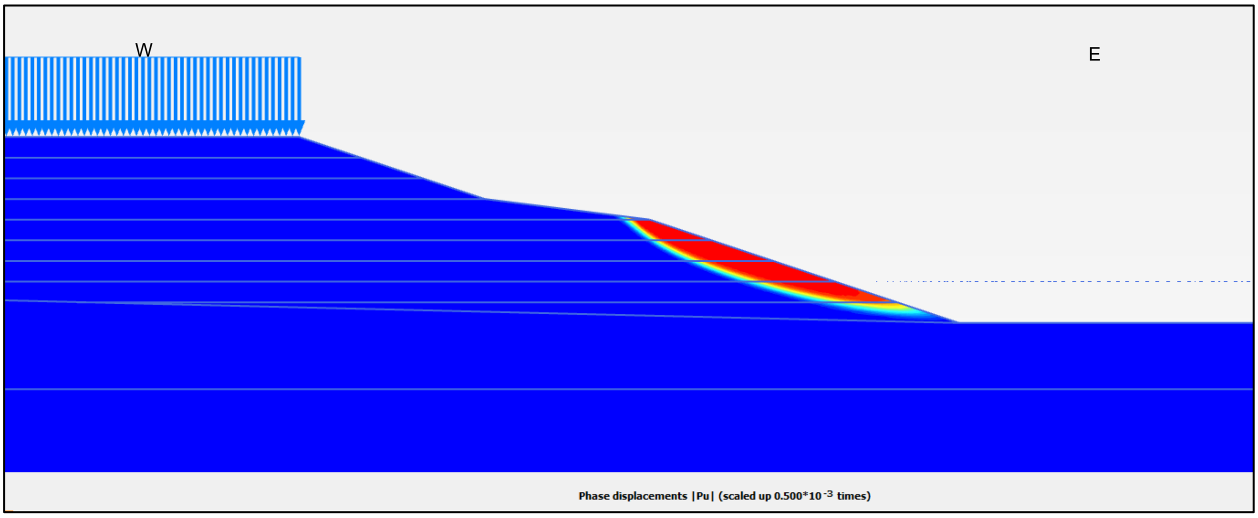


Figure 17: FoS analysis for Section C-C' Cohesive - long-term stage



Maximum settlements and FoS values for short and long-term conditions are summarised in Table 11.

7.3.1 Sensitivity Analysis

It is important to highlight that the geotechnical properties and characteristics of the bund material may vary widely depending on the class of material used. Therefore, results from a sensitivity analysis, assessing the influence of weaker cohesive material parameters on total settlement, are also provided. This was conducted by factoring the cohesive fill Cu and E’ values to 70% and 40% of their original value. It must be noted that the long-term parameters will have to remain as the previously stated minimum granular strength, or risk slope failure.

Table 11: Summary of results – Section C-C'.

Model	S-T Max Settlement (mm)	L-T Max Settlement (mm)	S-T FoS	L-T FoS
C-C’ Granular	227	241	>1.25	>1.25
C-C’ Cohesive 50kPa	210	234	>1.25	>1.25
C-C’ Cohesive (70%)	221	247	>1.25	>1.25
C-C’ Cohesive (40%)	283	316	>1.25	>1.25

8. Monitoring

Full details regarding instrumentation, maintenance and monitoring are provided in the Landscape Bund Earthworks Specification Area 2 (RAD-WAT-A2EX-XX-SP-0023).

Settlement monitoring will comprise the use of vibrating wire piezometers and rod and plate monitors during construction and rod and plate, surface pins and surface triaxial tiltmeter sensors or laser survey targets to monitor post construction settlement.

During construction the contractor will also record the following:

- Any evidence of instability in the slopes surrounding the works area;
- Any evidence of potential instability within completed sections of slope;
- The consistency of ground conditions exposed through the course of the works against those assumed in design / shown on design drawings;
- General groundwater observations and the presence of any localised seepages;
- Prevailing weather conditions including short and long-range forecasts, with works to stop during period of high rainfall or forecast high winds.

Settlement Trigger Values during construction as well as close out monitoring criteria are provided in the Earthworks Specification (RAD-WAT-A2EX-XX-SP-0023).

9. Conclusions

An SRA was required as part of the waste recovery EP application to authorise the permanent deposit of waste on land as a recovery activity. This waste material is to comprise a small portion of the overall fill material for the landscape bunds located in Area 2.

The proposed landscape design consists of two bunds, to be constructed to a top level of 80mAOD from existing ground level.

The northern bund is the smaller of the two, with a maximum height of 8.5m and continuous 1 in 3 slopes from top to toe levels. The larger southern bund has a maximum height of approximately 12.0m and has a mid-level 1 in 8 berm separating upper and lower 1 in 3 slopes.

Three representative sections were chosen for settlement and slope stability analysis across the two bunds. These consisted of:

- Section A-A' – a typical section through the northern bund, in close proximity to the rail chord.
- Section B-B' – the tallest section of the bunds, but with no underlying Landfill.
- Section C-C' – the section with the thickest underlying Landfill layer.

The variable soil stratigraphy across Area 2 required the adoption of separate ground models for the analysis. This encompassed WBH103 for Section A-A', WBH111 for Section B-B', and WBH115 for section C-C'.

The geotechnical parameters for the engineered fill constructing the bunds have been taken as the minimum requirements calculated in the Landscape Bunds: Geotechnical Design Report, while the engineered fill for the rail chord have been based upon best professional assumptions.

The assumed loadings across all models comprised 10kN/m/m across the top of the bund, and 20kN/m/m for the rail chord.

The assumed construction sequence was modelled as 1m layers followed by a consolidation after each layer deposition.

A summary of results is presented in Table 12, with the maximum settlement occurring in the long-term stage of section B-B' for both granular and cohesive fill materials. The maximum settlement was experienced at the long-term stage for each representative section, with the greatest settlement occurring along section B-B', at 395mm. This compared to 235mm in section A-A' and 234mm in section C-C'.

The calculated settlements will need to be anticipated, and additional waste will be required to construct the bunds to the designed levels. Monitoring of settlement, slope movement, and pore water pressures will be required sporadically along the length of the bunds, with more extensive monitoring in areas that are in close proximity to the rail chord and the M25.

All sections satisfy EC7 design requirement of FoS>1.25.

A cohesive fill sensitivity analysis resulted in an increase of maximum short-term settlement from 210mm, to 221mm at 70% strength and 283mm at 40% strength. Maximum long-term settlement increased from 234mm, to 247mm at 70% strength and 316mm at 40% strength. A FoS of >1.25 was maintained throughout the sensitivity analysis, satisfying the EC7 design requirement.

Table 12: Summary of results from Plaxis analysis.

Section	S-T Max Settlement (mm)	L-T Max Settlement (mm)	S-T FoS	L-T FoS
A-A’ Granular	219	235	>1.25	>1.25
A-A’ Cohesive	180	210	>1.25	>1.25
B-B’ Granular	384	392	>1.25	>1.25
B-B’ Cohesive	361	395	>1.25	>1.25
C-C’ Granular	227	241	>1.25	>1.25
C-C’ Cohesive 50kPa	210	234	>1.25	>1.25
C-C’ Cohesive (70%)	221	247	>1.25	>1.25
C-C’ Cohesive (40%)	283	316	>1.25	>1.25

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