ENVIRONMENTAL PERMIT VARIATION APPLICATION – STABILITY RISK ASSESSMENT

CROFT QUARRY
MARION'S WAY
CROFT
LEICESTERSHIRE
LE9 3GP

Document Reference: AI1009/09.R0
June 2024

Project Quality Assurance
Information Sheet

ENVIRONMENTAL PERMIT VARIATION APPLICATION – STABILITY RISK ASSESSMENT CROFT QUARRY, MARION'S WAY, CROFT, LEICESTERSHIRE, LE9 3GP

Report Status : Draft

Report Reference : AI1009/09.R0

Report Date : June 2024

Prepared for : Aggregate Industries UK Limited

Prepared by : Sirius Environmental Limited
The Beacon Centre for Enterprise
Dafen
Llanelli
SA14 8LQ

Written by :

Joe Camfield MEng (Hons) GMICE
Senior Engineer

Reviewed by :

Dylan Thomas BSc (Hons) PGDip MCIWM
Principal Environmental Consultant

Approved by :

Andrew Kirk
Design Director

Revision	Date	Amendment Details	Author	Reviewer
0	June 2024	First Issue	JC	DT

CROFT QUARRY
MARION'S WAY
CROFT
LEICESTERSHIRE
LE9 3GP

ENVIRONMENTAL PERMIT VARIATION APPLICATION
STABILITY RISK ASSESSMENT

CONTENTS

LIST OF APPENDICES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Report Context

1.1.1 Sirius Environmental Limited (Sirius) has been commissioned by Aggregate Industries UK Limited ('AI'), to prepare an application to vary Environmental Permit: EPR/EB3708GW to add a waste recovery activity involving the permanent deposit of wastes to support the restoration of Croft Quarry, Marion's Way, Croft, Leicestershire, LE9 3GP. AI are seeking to commence restoration of the quarry which will bring the final restoration levels to below those of the surrounding natural ground levels. As part of this application, it is necessary to formulate a range of risk assessment documents, including the requirement to undertake a Stability Risk Assessment (SRA).

1.1.2 This SRA includes the assessment of the stability issues related to the construction of the quarry lining system and waste placement in the quarry, for both the main quarry void and the proposed extension area to be developed on the eastern side of the quarry. The basal contours of the existing quarry / proposed extension area, along with the construction details showing the proposed lining system construction methodology, are shown on **Drawing No.: AI1009/14/14**.

1.1.3 This SRA has been prepared using guidance contained within the Environment Agency R&D Technical Report P1-385/TR2 (hereinafter referred to as 'The Guidance').

1.1.4 This report should also be read in conjunction with the Environmental Setting and Site Design (ESSD) report (Doc. Ref.: AI1009/07) and the Hydrogeological Risk Assessment (HRA) report (Doc. Ref.: AI1009/08), which accompany the wider Environmental Permit application submission.

1.2 Outline of the Installation

1.2.1 Croft Quarry is located immediately to the north of the village of Croft and approximately 500m to the south-west of the village of Huncote, Leicestershire. The application site has a postcode of LE9 3GP and is approximately centred on a National Grid Reference (NGR) of SP 51269 96539.

1.2.2 The entire Croft Quarry site extends over an area of c. 111.5ha, of which the quarry void footprint will occupy c. 48ha. Access to the site is via Marion's Way, located along the southern boundary of the quarry, which connects to Coventry Road.

1.2.3 The existing site comprises operational mineral extraction areas, areas undergoing restoration, the current mineral processing plant, concrete block works and recycling and associated areas of hardstanding and open storage. These operations are set behind mature vegetation (including perimeter hedgerows) and developed woodland.

1.3 Site Topography

1.3.1 Croft Quarry is located on the eastern side of Croft Hill which rises to a summit at ~128mAOD immediately to the west of the quarry void at Croft Hill. Natural ground levels at Croft Quarry typically fall to the east and south towards the River Soar (south) and Thurlaston Brook (east).

1.3.2 The topography of land surrounding the quarry void is relatively flat lying with the exception of a landscaped hillside on the north-eastern boundary that is the product of overburden stripping.

1.3.3 A topographical survey of the quarry indicates that the rim of the quarry (at natural ground levels) typically ranges from c. 110mAOD in the west falling to c.80mAOD in the south, north and east.

1.3.4 The quarry has been worked in a series of benches to a maximum depth (January 2017) of c.–139mBOD giving a maximum quarry depth of up to 230m.

1.4 History of the Installation

1.4.1 Croft Quarry is a long-established hard rock quarry with extraction occurring since 1886. Croft Quarry expanded and in 1919 employed over 400 hands, the 1920's and 1930's saw the introduction of the concrete works that remains operational. In the 1980's Huncote Quarry and Croft Quarry merged creating the footprint visible today. 1995 saw the lateral extension granted planning permission by Leicestershire County Council in February 1995. The planning permission was subject to a Review of Mineral Planning Permissions (ROMP) by Leicestershire County Council in 2010. The current permission includes a further lateral extension and final restoration scheme for Croft Quarry which was approved by Leicestershire County Council on 12th January 2022.

1.5 Summary of Previous Work

<u>Croft Quarry Inert Infilling – Stability Risk Assessment (January 2022) – Report Reference AI1000/07.R1</u>

1.5.1 This Stability Risk Assessment (SRA) was prepared by Sirius Environmental Limited, on behalf of Aggregate Industries UK Limited, in October 2021. The SRA was prepared in support of an original application for a permit to support restoration of the quarry, which was subsequently withdrawn in agreement with the EA. The SRA assessed the stability of the waste tipping profile in Croft Quarry, during and following infilling. A large waste flank was modelled rising from the proposed western edge of the lateral extension area to the western sidewall of the existing quarry), as illustrated in Phase 4 in **Drawing No. AI1009/14/03.**

1.6 Conceptual Stability Site Model

1.6.1 The following sub-sections present a summary of the natural geological, geosynthetic, or fill materials (including engineered fill and un-engineered infill) used in the model, relating specifically to the components identified in the guidance contained within the Environment Agency R&D Technical Report P1385/TR2.

1.6.2 The information presented in this report has been compiled from a combination of the information in the PPC Permit Variation Application documents (ESSD and HRA), previous reports, ground investigation data (noted in Section 1.6.3) and groundwater monitoring data from the site.

<u>Geology and Ground Conditions</u>

1.6.3 The following information sources have been used as part of this review:

- The British Geological Survey (BGS) 1:50,000 scale Sheets 169 (Coventry) and 155 (Coalville) solid and drift editions;

- Logs of gas and groundwater monitoring boreholes installed between September and December 2017;
- Logs of historical boreholes drilled at and in the vicinity of the site (available from BGS Onshore Viewer); and
- Carney JN (2010). Magma mixing in the South Leicestershire diorite: evidence from an Ordovician pluton at Croft Quarry, Mercian Geologist, 17 (3). 166-172.

1.6.4 Unworked, superficial deposits at and surrounding the application site comprise the Oadby Member (Diamicton moraines of till with outwash sand and gravel deposits), particularly around the west and south of the quarry void. River Terrace Deposits (sands and gravels) dominate around the eastern edge of the application site. Additionally, alluvium associated with the River Soar and its tributaries is present to the north, south, and east of the Croft Quarry site.

1.6.5 Croft Quarry operations exist due to the local presence of an inlier of the South Leicestershire Diorite Complex. The exposure worked at Croft is part of a ~14km wide pluton. The pluton forms part of a larger series of small batholiths. This Ordovician age quartz-diorite is the commercially worked mineral at the Site.

1.6.6 The quartz-diorite intrusion is surrounded by various Triassic age mudstone, siltstone and sandstone members of the of the Mercia Mudstone Group, with the Edwalton Mustone Member identified to outcrop around the northern sections fo the quarry and differentiate members to south, although outcrops of the Cotsgrave Sandstone and Gunthorpe Mudstone Members are considered to be exposed along the northeastern quarry face.

1.6.7 The Mercia Mudstone Group was proven at the base of the superficial drift and made ground deposits in all boreholes surrounding the Croft Quarry void with the exception of BH01 (on the north-western side of the quarry). In BH01 the observed topsoil transitioned directly into the South Leicestershire Diorite Complex which was proven to lie beneath the Mercia Mudstone Group in all remaining boreholes. The Mercia Mudstone Group and South Leicestershire Diorite Complex surrounding the Croft Quarry void both comprised of weathered and fresh strata. The weathered Mercia Mudstone strata are described as reddish-brown mudstones which has been weathered to clay. This weathered clay occasionally contains thin layers of grey clay with silt. Typically, weathered strata of Mercia mudstone are between c 2m and 12m thick. As presented in **Table SRA1** below, the maximum thickness of Mercia Mudstone encountered was 70.5m (BH04A to the north of the site), which thickens away from the quarry.

1.6.8 The weathered strata of the South Leicestershire Diorite Complex are described as light brown in colour and any returns to the surface comprising of sand and angular fine to medium gravel fragments. As with the weathered Mercia Mudstone strata, the weathered diorite does not extend far beyond a depth of ~2m. Again, as observed in the Mercia Mudstone the thickness of the South Leicestershire Diorite Complex varies between each borehole. However, given that the no borehole reached the base of this unit it is assumed that it is over 238.5m thick.

1.6.9 A summary of the stratigraphy present within the vicinity of the quarry; derived from borehole logs generated during the installation of peripheral gas and groundwater monitoring wells, is provided in **Table SRA1** below.

Table SRA1: Summary of Geology in the Vicinity of Croft Quarry

Unit	Description	Locations Encountered	Minimum Thickness (m)	Maximum Thickness (m)
Topsoil	Silty sand locally gravelly sand	BH01, BH04A/B	0.5	3.5
Made Ground	Mostly poorly sorted diorite gravel with some imported gravel	BH02A/B, BH03A/B/C	0.5	3.0
Alluvium	Medium to coarse sand	BH04A/B	0.7	1.2
Glacial Till	Poorly sorted gravel clasts in a clayey sand to sandy clay matrix	BH02A/B, BH03A/B/C, BH04A/B	3.0	5.8
Mercia Mudstone Group	Thinly bedded dark brown mudstone, occasionally silty layers.	BH02A/B, BH03B/C, BH04A/B	21.1	70.5
South Leicestershire Diorite Complex	Very strong crystalline diorite with some mineral veining	BH01, BH02A/B, BH03B/C. BH04A/B	Unit not proven	>238.5

1.6.10 For the purposes of this SRA, the Mercia Mudstone and South Leicestershire Diorite have been modelled as a single bedrock unit. The bedrock unit has been modelled as a Quartz-Diorite type material (in terms of geotechnical properties); to best represent the properties the bedrock in the quarry at the levels where lining / infilling with waste will take place. The lining system / waste is only to be constructed against the lower Diorite bedrock.

1.6.11 No known faults influence the site. Coal Authority maps indicate that the site is not in a historical coal mining area.

<u>Hydrogeology and Groundwater</u>

1.6.12 The superficial river terrace deposits (present on the north and east of the site) are classified as a 'Secondary A' Aquifer whilst the Oadby Member (present on the western side of the site) is classified as a 'Secondary (Undifferentiated)' aquifer by the Environment Agency. Groundwater in both of these units is perched above the Mercia Mudstone Group. A study carried out by Hafren (2001) indicated that the superficial deposits surrounding Croft Quarry (sand and gravels) have a moderate to high intergranular hydraulic conductivity with values between 5.79×10^{-5} m/s and 6.24×10^{-4} m/s. Additionally, the hydraulic conductivity of the Oadby Member (present on the western side of the quarry) is considered to be comparable to that of the local Mercia Mudstone, this is due to it primarily consisting of clay with rare fragments of older(e.g. Jurassic) lithologies.

1.6.13 Groundwater monitoring data from the boreholes surrounding the site indicates that water levels within the superficial deposits to the east of the quarry void; recorded in BH03/A, are around 71.08mAOD and 73.47mAOD and are associated with surface water factures. The potential for vertical migration of groundwater into the underlying Mercia Mudstone is limited, due to the relatively low permeability of this strata. It is proposed that groundwater flow direction in the superficial deposits follows the dip of the Mercia Mudstone/Diorite boundary, away from the quarry void towards the south-east.

1.6.14 The Mercia Mudstone Group and the South Leicestershire Diorite Complex are classed as 'Secondary B aquifers', of a low permeability – the units may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. Laboratory triaxial permeability testing has shown that the Mercia Mudstone Group has an average permeability of 1.84×10^{-11} m/s.

1.6.15 Groundwater levels in the surrounding Mercia Mudstone; recorded in BH02/A, BH03/B and BH04/A, vary across the site, with levels to the north of the quarry (BH04/A) between 38.62mAOD and 41.93mAOD, 50.62mAOD to south of the quarry (BH02/A) and between 19.37mAOD and 21.99mAOD to the southeast of the quarry void (BH03/B). It is important to note that BH02/A has been reported as "dry" since January 2019 and no groundwater has been encountered. Groundwater flow in the Mercia Mudstone occurs in the fine sandstone, siltstone, and mudstone horizons, either along bedding planes or in discrete fractures. The groundwater levels recorded in the Mercia Mudstone indicate that groundwater flow through this unit is towards the south-east.

1.6.16 Monitoring data collected from piezometers within the Diorite aquifer between August 2018 to July 2021 indicates that groundwater levels within the Diorite are currently recorded at variable levels around the periphery of the site, and are shown to be consistently and substantially below those within the overlying Mercia Mustone aquifer. Where heads in the two aquifer units are measured by adjacent piezometer pairs (BH3B & BH3C and BH4A & BH4B), the separation of groundwater levels during the monitoring period between the aquifers ranges between ~56m and ~70m.

1.6.17 The water level contained within the quarry sump is currently c.136mBOD; average groundwater elevations measured at piezometers BH01, BH02B, BH3C and BH4B (within the Diorite aquifer), all positioned at increasing distance from the void, are 70.5mBOD, 55.5mBOD, 50.5mBOD and 17mBOD respectively, which indicates that groundwater levels generally fall on approach to the quarry void, indicating a cone of depression towards the void.

1.6.18 It is evidenced from other abandoned quarries in the South Leicestershire Diorite Complex that water levels rebound to entirely inundate the void. This would suggest that prior to the commencement of dewatering at Croft Quarry the groundwater levels within the Quartz Diorite are most likely to have been close to ground surface. It is therefore anticipated that groundwater levels within the Diorite will start to rise as infilling of the void progresses.

1.6.19 Considering the above information, for this SRA the groundwater level in the Diorite bedrock immediately adjacent to the quarry has been modelled at the base of the quarry at the commencement of infilling, then progressively rising in conjunction with the construction of the quarry lining system / waste infilling.

Stability Section Selection

1.6.20 A cross-sectional model has been utilised for the assessments carried out in this SRA. The cross-section includes quarry faces of varying gradients separated by horizontal benches.

1.6.21 The cross-section is a hybrid cross-section incorporating the key geometrical features of the quarry requiring assessment, rather than a cross-section with a specific location on site. The cross-section includes a range of typical gradients for the steep quarry faces, ensuring that the lining system construction / waste placement can be assessed for a range of scenarios applicable to the quarry.

Basal Subgrade Model

1.6.22 The basal subgrade for the quarry is comprised of bedrock of the South Leicestershire Diorite Complex, generally described as very strong crystalline diorite with some mineral veining.

1.6.23 Any material on the quarry floor which is deemed to be unsuitable or which may lead to soft spots beneath the quarry lining system shall be removed prior to lining the base of the quarry. Any engineered fill material required to be placed to create a suitably even formation for the lining system shall be placed and compacted in layers such that it creates a firm formation for the lining system.

Side-Slope Subgrade Model

1.6.24 The side-slope subgrade for the quarry highwalls is predominantly comprised of bedrock of the South Leicestershire Diorite Complex, generally described as very strong crystalline diorite with some mineral veining. The upper quarry highwalls (above ~10m BOD - ~20mBOD) are comprised of Mercia Mudstone, generally described as thinly bedded dark brown mudstone with occasional silty layers. As described in Section 1.6.10 above, both of these types of rock have been modelled as a single bedrock unit.

1.6.25 The quarry faces modelled range between approximately 45° and 85°, with horizontal benches modelled between each face. This is typical of the quarry highwalls throughout the quarry.

1.6.26 Any material on the benches on the quarry faces which is deemed to be unsuitable or may lead to soft spots beneath the quarry lining system shall be removed prior to lining these areas. Any engineered fill material required to be placed to create a suitably even formation for the lining system shall be placed and compacted in layers such that it creates a firm formation for the lining system.

1.6.27 As discussed in Section 1.6.18 above, groundwater levels within the Diorite bedrock (adjacent to the quarry sidewalls) are likely to rise as infilling of the quarry progresses. Ongoing water management will be necessary throughout the infilling of the quarry to manage the small volumes of groundwater influxes from the Diorite, overlying Mercia Mudstone and superficial deposits, together with the anticipated rainfall runoff volumes from the waste filled areas.

Basal Lining System Model

1.6.28 A lining system is required to be constructed on the base and side-slopes of the quarry, to prevent discharge of hazardous substances to groundwater. The lining system is to be constructed from suitable imported or site-won cohesive material.

1.6.29 The basal lining system of the quarry shall be comprised of a minimum 0.5m (500mm) thick Artificially Established Geological Barrier (AEGB), which shall be compacted to achieve a permeability (hydraulic conductivity) of $k=1x10^{-8}$ m/s or lower.

1.6.30 The AEGB material may also be placed as engineered fill beneath the lining system, where required to achieve an even formation for the 0.5m thick liner.

1.6.31 The basal lining system modelled is shown in the model geometry printouts in **Appendix SRA1**.

Side-Slope Lining System Model

1.6.32 A lining system is required to be constructed on the base and side-slopes of the quarry, to conform with the requirements of Schedule 22 of the EPRs. The lining system is to be constructed from suitable imported or site-won cohesive material.

1.6.33 The side-slope lining system of the quarry shall be comprised of a 1m (1,000mm) thick Artificially Established Geological Barrier (AEGB), which shall be compacted to achieve a permeability (hydraulic conductivity) of $k=1x10^{-8}$ m/s or lower.

1.6.34 The AEGB material may also be placed as engineered fill beneath the lining system, where required to achieve an even formation for the 1m thick liner.

1.6.35 Due to the steepness of the quarry faces, the side-slope liner will be required to be constructed in lifts (proposed to be 2m high), as shown in the construction details on **Drawing AI1009/14/14**. Each lift shall be buttressed non-degradable wastes prior to the construction of the next lift.

1.6.36 The side-slope lining system has been modelled up to a level of 10mAOD. The final level is proposed to be higher (18mAOD), but the level of 10mAOD is sufficient to model the liner construction in lifts on the upper near-vertical quarry face on the cross section.

1.6.37 The side-slope lining system modelled is shown in the model geometry printouts in **Appendix SRA1**.

Waste Mass Model

1.6.38 The site will accept selected non-biodegradable, non-hazardous wastes. Such wastes which will not undergo any significant physical, chemical or biological transformations and as such will result in negligible pollution potential with respect to the production of landfill gas or leachate.

1.6.39 The waste is to be placed in horizontal layers from the base of the quarry upwards and is to be built-up in conjunction with the side-slope lining system. Following the construction of each lift of the side-slope lining system, the lift is to be buttressed with waste prior to the construction of the next lift. Following the construction of each lining system lift, the waste may be infilled slightly higher (2m) than the lining system in the middle of the quarry, with a lower bench left near the edge of the lining system to ensure the top of the lining system is kept clear and is accessible. This area may also serve as a rock trap for any falling rocks from the faces above. Low flanks in the waste between such areas and the waste in the middle of the quarry have been modelled at a gradient of 1 in 2. The proposed construction details showing how each lift of the lining system is to be buttressed with waste are shown on **Drawing AI1009/14/14**.

1.6.40 No water level has been modelled within the waste, as it will take many years (and likely decades) for any groundwater level within the waste mass, originating from seepages from fissures in the quarry highwalls, to become established. This is due to the low permeability nature of the quarry liner / waste material.

1.6.41 To allow for safe working of the mineral reserve in the lateral extension areas as restoration fill levels rise above the base of the proposed extraction profile a temporary waste flank may be constructed in the main quarry, rising from the same level as the base of the extension area (on the eastern side of the main quarry) to the western quarry highwall. This waste flank could rise to be up to ~30m high, whilst allowing for a flat bench level on the waste surface (a minimum of 20m wide) to be left between the base of the flank and the extension area. The stability of this waste flank has been assessed in the report 'Croft Re: Quarry Inert Infilling – Stability Risk Assessment', document reference AI1000/07.R1, dated January 2022.

Capping System Model

1.6.42 The capping system for the infilled quarry shall be comprised of a 0.5m (500mm) thick Artificially Established Geological Barrier (AEGB), which shall be compacted to achieve a permeability (hydraulic conductivity) of $k=1x10^{-8}$ m/s or lower. The capping liner shall be covered with a 1,000mm thick restoration soils layer.

1.6.43 The capping system is to be constructed as an attenuation layer to prevent flow of any contaminated groundwater upwards from the waste mass into the proposed wetland above. The capping system is to be tied-into the top of the quarry side-slope lining system, and slope down towards the middle of the quarry at a gradient of 1 in 10, to form a bowl-shaped depression. The construction detail for the capping system is shown on **Drawing AI1001/14/14**.

Quarry Construction / Infilling Phases

1.6.44 The phasing used in the modelling is presented in **Table SRA2** below. It has been assumed that during the 1st year of quarry lining / infilling a 30m depth of waste will be placed, during the 2nd year a 16m depth, during the 3rd-5th years an 8m depth each year, then finally a 6m depth each year until completion of infilling.

Table SRA2: Liner Construction / Waste Filling Timeline Used in the Analyses

Phase Description	Timeframe
1st Year: 2m High Liner Lift Construction (x15)	1 day per lift
1st Year: Buttress Liner Lifts with Waste (infill bench area) (x15)	1 day per lift buttress
1st Year: Waste Placement Across Quarry following each Liner Lift (x15)	22 days per waste placement phase
2nd Year: 2m High Liner Lift Construction (x8)	1 day per lift
2nd Year: Buttress Liner Lifts with Waste (infill bench area) (x8)	1 day per lift buttress
2nd Year: Waste Placement Across Quarry following each Liner Lift (x8)	44 days per waste placement phase
3rd-5th Years: 2m High Liner Lift Construction (x12)	1 day per lift
3rd-5th Years: Buttress Liner Lifts with Waste (infill bench area) (x12)	1 day per lift buttress
3rd-5th Years: Waste Placement Across Quarry following each Liner Lift (x12)	89 days per waste placement phase
Final Years: 2m High Liner Lift Construction (x15)	1 day per lift
Final Years: Buttress Liner Lifts with Waste (infill bench area) (x15)	1 day per lift buttress
Final Years: Waste Placement Across Quarry following each Liner Lift (x15)	120 days per waste placement phase

2.0 STABILITY RISK ASSESSMENT

2.1 Introduction

2.1.1 The six principal components of the conceptual stability site model have been considered and the various elements of that component have been assessed.

2.1.2 The principal components considered are:

- Basal subgrade;
- Side-slope subgrade;
- Basal lining system;
- Side-slope lining system;
- Waste; and
- Capping System.

2.2 Risk Screening

2.2.1 Issues relating to stability and deformability of the principal components of the conceptual stability site model have been subject to a preliminary review to determine the need to undertake further detailed geotechnical analyses. The following sections present the results of this screening exercise.

<u>Basal Subgrade Screening</u>

2.2.2 The factors that influence the stability and deformability of the basal subgrade are considered in **Table SRA3** below.

Table SRA3: Stability and Deformability Components for Basal Subgrade

Stability / Deformability Component	Screening Component	Screening Assessment
Excessive Deformation	Compressible Subgrade	The immediate subgrade for the basal lining system comprises bedrock of the South Leicestershire Diorite Complex. The bedrock is unlikely to present compressibility issues for the quarry subgrade. However, for any modelling the bedrock materials shall be given representative stiffness values, so any issues relating to compressibility can be assessed.
	Basal Heave	*Heave due to Unloading*: No significant further excavation of the quarry is anticipated during the works, and the bedrock material is relatively incompressible. Therefore, no heave of the quarry base due to unloading is anticipated. *Heave due to Groundwater*: Groundwater influxes from the Diorite, overlying Mercia Mudstone and superficial deposits will be controlled by ongoing water management during the lining / infilling of the quarry. Although groundwater seepages from the basal subgrade (behind the basal lining system) may occur, as the Diorite bedrock is relatively incompressible, heave of the basal subgrade is not anticipated.
	Cavities in Subgrade	None anticipated

Side-Slope Subgrade Screening

2.2.3 The factors that influence the stability and deformability of the side-slope subgrade are considered in **Table SRA4** below.

Table SRA4: Stability and Deformability Components for Side-Slope Subgrade

Stability / Deformability Component	**Screening Component**	**Screening Assessment**
Excessive Deformation	Compressible Subgrade	The immediate subgrade for the side-slope lining system comprises bedrock of the Mercia Mudstone Group and the South Leicestershire Diorite Complex. These bedrock materials are unlikely to present compressibility issues for the quarry subgrade. However, for any modelling the bedrock materials shall be given representative stiffness values, so any issues relating to compressibility can be assessed.
	Heave	*Heave due to Unloading*: No significant further excavation of the quarry is anticipated during the works, and the bedrock material is relatively incompressible. Therefore, no heave of the quarry side-slope due to unloading is anticipated. *Heave due to Groundwater*: Groundwater influxes from the Diorite, overly Mercia Mudstone and superficial deposits will be controlled by ongoing water management during the lining / infilling of the quarry. Although groundwater seepages from the side-slope subgrade (behind the side-slope lining system) may occur, as the Diorite bedrock is relatively incompressible, heave of the side-slope subgrade is not anticipated.
	Cavities in Subgrade	None anticipated
	Quarry Highwall Instability	The quarry faces have been cut at angles generally between 1 in 1 (45°) and vertical from the Mercia Mudstone / Diorite bedrock and have remained stable in the medium-long term. Stability failures occurring within the quarry faces are deemed to be unlikely and have not been assessed further in this SRA, however there is a risk of falling material (loose rock) above the working areas for construction. This risk and suitable mitigation measures will be highlighted further in this SRA and be considered during the design / construction phase of the quarry lining system and waste infilling operations.

Basal Lining System Screening

2.2.4 The factors that influence the stability of the quarry basal lining system are considered in **Table SRA5** below.

Table SRA5: Stability Components for Basal Lining System

Component of Stability Site Model	Screening Component	Screening Assessment
Basal Lining System	Stability	The basal subgrade consists of bedrock of the South Leicestershire Diorite Complex. Due to the high strength and low compressibility of these materials, it is unlikely that any significant instability / compressibility will occur in the subgrade, which could affect the stability/deformability of the basal lining system. Therefore, the stability of the basal lining system has not been assessed further in this SRA.
	Compressible Subgrade	The immediate subgrade for the basal lining system comprises bedrock of the South Leicestershire Diorite Complex. The bedrock is unlikely to present compressibility issues for the quarry subgrade. However, for any modelling it shall be given representative stiffness values, so any issues relating to compressibility can be assessed.
	Cavities	None anticipated.
	Basal Heave	*Heave due to Unloading*: Not anticipated (see **Table SRA3**). *Heave due to Groundwater*: Due to small groundwater influxes beneath the basal lining system (from the Diorite bedrock) some groundwater pressure may be exerted on the base of the lining system. However, any such pressure is likely to take some time to build-up, and the placement of the waste above the lining system will generate downward pressures on the lining system (due to the weight of the waste), which will counteract the groundwater pressures. Therefore, the risk of heave of the basal lining system is considered low, and has not been addressed further in this SRA.

Side-Slope Lining System Screening

2.2.5 The factors that influence the stability of the quarry side-slope lining system are considered in **Table SRA6** below.

Table SRA6: Stability Components for Side-Slope Lining System

Component of Stability Site Model	Screening Component	Screening Assessment
Side-Slope Lining System (Unconfined)	Stability	The side-slope lining system will be least stable when the slope is un-confined, and no waste has been placed against it. As waste is placed against the side-slope, the factor of safety will increase as the waste provides a passive wedge (confinement) at the base of the slope. The unconfined slopes will be assessed in this SRA. Realistic time scales will be utilised in the modelling to check the stability of the lining system. Appropriate strength / permeability parameters for the lining materials shall be utilised, to ensure that the effects of excess pore water pressures on stability are properly assessed. The side-slope lining system shall be modelled as constructed in lifts, which shall be confined by waste following their construction.
	Heave	*Heave due to Unloading*: Not anticipated (see **Table SRA4**). *Heave due to Groundwater*: Due to small groundwater influxes behind the side-slope lining system (from the Diorite bedrock) some groundwater pressure may be exerted on the back of the lining system. However, any such pressure is likely to take some time to build-up, and the placement of the waste against the lining system will generate pressures against the front of the lining system which will counteract the groundwater pressures. Therefore, the risk of heave of the side-slope lining system is considered low, and has not been addressed further in this SRA.
Side-Slope Lining System (Confined)	Stability	Confinement of the side-slope lining system will increase the factor of safety from that of the un-confined system, as even new waste at shallow depths will have some stiffness and will provide passive resistance and added stability for the system. The confined slopes will be assessed in this SRA.

Waste Mass Screening

2.2.6 The factors that influence the stability of the waste are considered in **Table SRA7** below.

Table SRA7: Stability Components for Waste Slopes

Failure Mode Assessed	**Screening Component**	**Screening Assessment**
Failure Wholly in Waste	Stability	The height, gradient, and timeframe of filling will affect the stability of the waste. The waste is likely to be low permeability material; when the waste is placed there may potentially be a build-up of excess pore water pressure within the material, which could cause instabilities in the waste mass (due to no increase in effective stress in the material in the short-term). The waste will be placed in horizontal layers, resulting in only low slopes (~2m high) in the waste, improving the stability. Instability within such low waste flanks is considered to be unlikely. The stability of the waste placement phases in has not been assessed further in this SRA. However, any potential instabilities of the low waste flanks will be assessed during the liner construction stability phases, during which these flanks are unconfined in the modelling. The stability of the proposed high temporary waste flank which may be present in the main quarry should the extension area of the quarry be developed also requires assessment. This has been assessed in report reference: AI1000/07.R1.
Failure Involving Liner and Waste	Stability	Waste placement and the height and gradient of the waste may allow the waste to fail along the lining system / along the interface between the lining system and the quarry highwall. This shall be further assessed in this SRA.

Capping System Screening

2.2.7 The factors that influence the stability of the capping system are considered in **Table SRA8** below.

Table SRA8: Stability Components for Capping System

Component of Stability Site Model	**Screening Component**	**Screening Assessment**
Capping System	Stability	The capping system is to be constructed a very shallow gradients (~1 in 10) sloping towards the middle of the restored quarry. As such instability of the capping slopes is not anticipated and has not been considered further in this SRA.

2.3 Justification for Modelling Approach and Software

2.3.1 In order to perform a comprehensive Stability Risk Assessment (SRA), the components of the quarry stability model have to be considered not only individually, but also in conjunction with one another, where relevant. Any analytical techniques adopted for such an assessment should adequately represent all of the considered scenarios for both the un-confined and confined conditions (where appropriate). The methodology and the software should also achieve the desired output parameters for the assessment. This equates to the determination of factors of safety for stability assessments.

2.3.2 The analytical methods used in this stability risk assessment include:

- **Finite element analyses** for the determination of the **stability of the quarry lining system / waste**, following construction of each lift of the lining system, and following buttressing each lift with waste, and the associated **calculation of factors of safety**.

Finite Element Analyses

2.3.3 The proprietary software **PLAXIS 2D** (2021) has been used for the stability assessments. This is a two-dimensional finite element programme intended for the analysis of deformation and stability in geotechnical engineering. It is equipped for the simulation of non-linear, time dependent and anisotropic behaviour of soils and rock. In addition, since soil is multi-phase material, special procedures are required to deal with hydrostatic and non-hydrostatic pore pressures in the soil. **PLAXIS 2D** was originally developed for geotechnical engineers studying river embankments on the soft soils of the lowlands of Holland. In subsequent years, **PLAXIS 2D** has been extended to cover most other areas of geotechnical engineering. It is therefore well suited for use in the Croft Quarry Stability Risk Assessment.

Phi-C Reduction

2.3.4 A safety analysis in PLAXIS is undertaken by reducing the strength parameters of the soils. This process is termed 'Phi-C reduction' and is carried out as a separate calculation mode. Phi-C reduction is used when it is required to calculate a factor of safety, for the situation under consideration.

2.3.5 In the Phi-C reduction approach, the strength parameters tan ϕ and c of the soils (and interface shear strengths) are incrementally reduced until failure of the system occurs. The strengths of interfaces, if used, are reduced in the same way. The strength of structural objects like plates and anchors are not influenced by the Phi-C reduction.

2.3.6 The total multiplier ΣMsf is used to define the value of the soil strength parameters as a given stage in the analysis:

$$\sum Msf = \frac{\tan \varphi_{input}}{\tan \varphi_{reduced}} = \frac{c_{input}}{c_{reduced}}$$

2.3.7 A Phi-C reduction calculation is performed using the load advancement number of steps procedure. The incremental multiplier Msf is used to specify the increment of the strength reduction of the first calculation step. The increment is by default set to 0.1, which is generally found to be a good starting value. The strength parameters are successively reduced automatically until all additional steps have been performed. If this case, the factor of safety can be given by:

$$SF = \frac{}{\textit{strength at failure}} = \text{value of } \sum Msf \text{ at failure}$$

2.3.8 If a failure mechanism has not fully developed, then the calculation is repeated with a larger number of additional steps. It should be noted that the Phi-C process shows the failure mode that is most likely to occur for the given scenario and parameters; and other failure modes may also be relevant (but less likely to occur) in the case analysed.

2.3.9 To capture the failure of the system accurately, the use of arc-length control in the iteration procedure is required. The use of a tolerated error of no more than 3% is also required. Both requirements are complied with when using the Standard setting of the Iterative procedure.

2.3.10 When using Phi-C reduction in combination with advanced soil models, these models will actually behave as a standard Mohr-Coulomb model, since stress-dependant stiffness behaviour and hardening effects are excluded. The stress-dependent stiffness modulus (where this is specified in the advanced model) at the end of the previous step is used as a constant stiffness modulus during the Phi-C reduction calculation.

2.3.11 For slopes, the **Phi-C reduction** approach resembles the method of calculating safety factors as conventionally adopted in traditional slip-circle analyses.

2.4 Selection of Appropriate Factors of Safety

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

2.4.2 The factor of safety adopted for each component of the model would be related to the consequences of a failure.

2.4.3 BS6031 - Code of Practice for Earthworks (Clause 6.5.1.2 Safety Factors) states that suitable safety factors in a particular case can only be arrived at after careful consideration of all the relevant factors, and the exercise of sound engineering judgement. The factors to be considered include:

- The complexity of the soil conditions;
- The adequacy of the site investigation;
- The certainty with which the design parameters represent the actual in-situ conditions;
- The length of time over which the stability has to be assured;
- The likelihood of unfavourable changes in groundwater regime in the future;
- The likelihood of unfavourable changes in the surface profile in the future;
- The speed of any movement which might take place; and
- The consequences of any failure.

2.4.4 A minimum factor of safety of 1.3 is considered acceptable for stability, if reasonably conservative values are used. Where temporary waste flanks are to be constructed which will only be in place for up to several months, a minimum factor of safety of 1.2 is considered acceptable for stability of such waste flanks.

2.5 Justification for Geotechnical Parameters Selected for Analysis

2.5.1 Geotechnical data for the stability analysis has been obtained from several sources. These sources include previous stability risk assessments, the ESSD and HRA reports comprising part of this Permit Variation Application, site investigation information, and Sirius' recent experience for other stability risk assessment projects. The parameters selected for material properties consider the analysis to be undertaken, analysis previously undertaken and existing conditions on site.

2.5.2 The AEGB to be constructed for the basal and side-slope lining system shall be comprised of cohesive, low permeability soils. The permeability of the AEGB is required to be $<1x10^{-8}$ m/s. However following compaction of the lining system material, the actual permeability of the AEGB is likely to be lower. The permeability of the AEGB has been set at $5x10^{-9}$ m/s. The effective strength parameters for the AEGB have been set at c'=5kPa and ϕ'=25°, which are considered representative of a cohesive engineered fill material.

2.5.3 The non-biodegradable, non-hazardous waste is also likely to predominantly consist of cohesive, low permeability soils, which will be placed and informally compacted (with a roller) in horizontal layers. Therefore, the permeability of the waste has also been set at $5x10^{-9}$ m/s.

2.5.4 The bedrock parameters modelled have been chosen to represent a Quartz-Diorite type rock. The permeability of the bedrock has been set at a relatively high value of $1x10^{-4}$ m/s, which reflects the presence of fissures in the bedrock in the locality of the quarry, which create pathways for groundwater flow.

2.6 Summary of Material Parameters for Finite Element Analyses

2.6.1 **Table SRA9** below summarises the effective stress parameters utilised in the finite element analyses.

Table SRA9: Summary of Effective Stress Material Parameters for Finite Element Analyses (Hardening Soil Model)

Material	Unit Weight (dry-wet)	Effective Cohesion (c')	Effective Angle of Friction (ϕ')	Permeability (k)	Stiffness Parameters			
					E_{50}^{ref}	E_{oed}^{ref}	E_{ur}^{ref}	Power (m)
	kN/m³	kN/m²	°	m/s	kN/m²	kN/m²	kN/m²	-
AEGB (liner)	19.0 - 20.0	5.0	25.0	5.0×10^{-9}	6,000	6,000	18,000	0.75
Infill (Waste)	19.0 - 20.0	5.0	25.0	5.0×10^{-9}	4,000	4,000	12,000	0.75

2.6.2 **Table SRA10** below summarises bedrock parameters utilised in the finite element analyses.

Table SRA10: Summary of Bedrock Parameters for Finite Element Analyses (Hoek-Brown Rock Model)

Material	Unit Weight (dry-wet)	E'_{rm}	v'(nu)	$\|\sigma_{ci}\|$	m_i	GSI	D	Permeability (k)
	kN/m³	kN/m²	-	-	kN/m²	kN/m²	kN/m²	m/s
Bedrock	28.0 - 29.0	500×10^{3}	0.30	175×10^{3}	25.0	60.0	1.0	$k = 1\times10^{-4}$

2.6.3 A PLAXIS printout showing the full set of material parameters used in the modelling is presented in **Appendix SRA1**.

3.0 ANALYSIS

3.1 Introduction

3.1.1 The areas of Croft Quarry which require analysis are:

- **Lining System Construction and Waste Stability Analysis**: The stability of the AEGB and waste, following construction of each lift of the lining system, and buttressing each lift with waste, using **finite element analysis**.

3.2 Liner Construction and Waste Stability Analysis

3.2.1 A summary of the factors of safety from the PLAXIS Phi-C reduction runs for the stability model are presented in **Table SRA11**, **Table SRA12**, **Table SRA13** and **Table SRA14** below. These tables represent the results for side-slope AEGB construction lifts 1-15 (1^{st} year), 16-23 (2^{nd} year), 24-35 (3^{rd}-5^{th} years), 36-50 (final years), respectively. The results include the stability of each side-slope AEGB construction phase, and each buttressing of the AEGB with waste phase. Graphical representations of the analyses (including failure modes) for every 5th lift of the lining system / waste buttressing are shown in **Appendix SRA2**.

3.2.2 For the 3^{rd}-5^{th} years and final years models, the 2m high AEGB lifts were modelled as buttressed with waste during their construction, such that no more than a 1m vertical height of the AEGB is unconfined at any one time. This was required during the analysis to ensure that instabilities in the AEGB lifts (for lifts 24-50) did not occur.

Table SRA11: Summary of Phi-C Reduction Runs for Stability and Resultant Factors of Safety (1st Year)

Construction Lift Number	Side-Slope Liner AEGB Lift		Waste Buttress Against AEGB Lift	
	Critical Slope Identified During Analysis	Factor of Safety	Critical Slope Identified During Analysis	Factor of Safety
1	Circular Failure though AEGB Lift	1.674	Circular Failure through temporary waste flank	1.582
2	Circular Failure through AEGB Lift	1.404	Circular Failure through Existing Rock Face	4.056
3	Circular Failure through temporary waste flank	1.332	Circular Failure through Existing Rock Face	3.980
4	Circular Failure through temporary waste flank	1.239	Circular Failure through Existing Rock Face	4.086
5	Circular Failure through temporary waste flank	1.197	Circular Failure through Existing Rock Face	4.081
6	Circular Failure through temporary waste flank	1.219	Circular Failure through Existing Rock Face	4.091
7	Circular Failure through temporary waste flank	1.619	Circular Failure through Existing Rock Face	4.045
8	Local Failure through Existing Rock Face	1.645	Circular Failure through Existing Rock Face	4.097
9	Circular Failure through AEGB Lift	1.401	Circular Failure through Existing Rock Face	4.081
10	Circular Failure through temporary waste flank	1.414	Local Failure through Existing Rock Face	4.071
11	Circular Failure through temporary waste flank	1.283	Circular Failure through Existing Rock Face	4.046
12	Circular Failure through temporary waste flank	1.241	Circular Failure through Existing Rock Face	4.071
13	Circular Failure through temporary waste flank	1.287	Circular Failure through Existing Rock Face	4.054
14	Circular Failure through temporary waste flank	1.307	Circular Failure through Existing Rock Face	4.066
15	Circular Failure through AEGB Lift	1.307	Circular Failure through Existing Rock Face	4.027

Table SRA12: Summary of Phi-C Reduction Runs for Stability and Resultant Factors of Safety (2nd Year)

Construction Lift Number	Side-Slope Liner AEGB Lift		Waste Buttress Against AEGB Lift	
	Critical Slope Identified During Analysis	Factor of Safety	Critical Slope Identified During Analysis	Factor of Safety
16	Circular Failure through Liner Lift	1.306	Local Failure through Existing Rock Face	4.052
17	Circular Failure through Liner Lift	1.368	Circular Failure through Existing Rock Face	4.055
18	Circular Failure through Temporary Waste Flank	1.370	Circular Failure through Existing Rock Face	4.042
19	Circular Failure through Temporary Waste Flank	1.327	Circular Failure through Existing Rock Face	4.085
20	Circular Failure through Temporary Waste Flank	1.327	Circular Failure through Existing Rock Face	4.103
21	Circular Failure through Temporary Waste Flank	1.345	Circular Failure through Existing Rock Face	4.134
22	Circular Failure through Temporary Waste Flank	1.325	Circular Failure through Existing Rock Face	4.133
23	Circular Failure through Temporary Waste Flank	1.325	Circular Failure through Existing Rock Face	4.148

Table SRA13: Summary of Phi-C Reduction Runs for Stability and Resultant Factors of Safety (3rd-5th Years)

Construction Lift Number	Side-Slope Liner AEGB Lift		Waste Buttress Against AEGB Lift	
	Critical Slope Identified During Analysis	Factor of Safety	Critical Slope Identified During Analysis	Factor of Safety[1]
24	Circular Failure through Lower 1m of Liner Lift	1.920	Circular Failure through Top 1m of Liner Lift	2.218
25	Circular Failure through Temporary Waste Flank	1.599	Circular Failure through Top 1m of Liner Lift	2.008
26	Circular Failure through Temporary Waste Flank	1.502	Circular Failure through Top 1m of Liner Lift	2.012
27	Circular Failure through Temporary Waste Flank	1.494	Circular Failure through Top 1m of Liner Lift	2.032
28	Circular Failure through Temporary Waste Flank	1.490	Circular Failure through Top 1m of Liner Lift	2.036
29	Circular Failure through Temporary Waste Flank	1.449	Circular Failure through Top 1m of Liner Lift	2.041
30	Circular Failure through Temporary Waste Flank	1.436	Circular Failure through Top 1m of Liner Lift	1.872
31	Circular Failure through Temporary Waste Flank	1.585	Circular Failure through Top 1m of Liner Lift	1.923
32	Circular Failure through Temporary Waste Flank	1.485	Circular Failure through Top 1m of Liner Lift	1.920
33	Circular Failure through Temporary Waste Flank	1.494	Circular Failure through Top 1m of Liner Lift	1.927
34	Circular Failure through Temporary Waste Flank	1.438	Circular Failure through Top 1m of Liner Lift	1.944
35	Circular Failure through Temporary Waste Flank	1.412	Circular Failure through Top 1m of Liner Lift	1.954

1. *Lower 1m of waste buttress placed during construction of upper 1m of 2m high AEGB lift, such that no more than 1m (vertically) of AEGB is unconfined at any one time.*

Table SRA14: Summary of Phi-C Reduction Runs for Stability and Resultant Factors of Safety (Final Years)

Construction Lift Number	Side-Slope Liner AEGB Lift		Waste Buttress Against AEGB Lift	
	Critical Slope Identified During Analysis	Factor of Safety	Critical Slope Identified During Analysis	Factor of Safety[1]
36	Circular Failure through Temporary Waste Flank	1.996	Circular Failure through Top 1m of Liner Lift	2.023
37	Circular Failure through Temporary Waste Flank	1.611	Circular Failure through Top 1m of Liner Lift	2.017
38	Circular Failure through Temporary Waste Flank	1.485	Circular Failure through Top 1m of Liner Lift	2.168
39	Circular Failure through Temporary Waste Flank	1.844	Circular Failure through Top 1m of Liner Lift	1.899
40	Circular Failure through Temporary Waste Flank	1.565	Circular Failure through Top 1m of Liner Lift	1.906
41	Circular Failure through Temporary Waste Flank	1.550	Circular Failure through Top 1m of Liner Lift	1.899
42	Circular Failure through Temporary Waste Flank	1.510	Circular Failure through Top 1m of Liner Lift	1.920
43	Circular Failure through Temporary Waste Flank	1.492	Circular Failure through Top 1m of Liner Lift	1.954
44	Circular Failure through Temporary Waste Flank	1.472	Circular Failure through Top 1m of Liner Lift	1.978
45	Circular Failure through Temporary Waste Flank	1.462	Circular Failure through Top 1m of Liner Lift	2.017
46	Circular Failure through Temporary Waste Flank	1.447	Circular Failure through Top 1m of Liner Lift	1.848
47	Circular Failure through Temporary Waste Flank	1.440	Circular Failure through Top 1m of Liner Lift	1.837
48	Circular Failure through Temporary Waste Flank	1.459	Circular Failure through Top 1m of Liner Lift	1.886
49	Circular Failure through Temporary Waste Flank	1.405	Circular Failure through Top 1m of Liner Lift	1.886
50	Circular Failure through Temporary Waste Flank	1.181	Circular Failure through Top 1m of Liner Lift	1.412

1. *Lower 1m of waste buttress placed during construction of upper 1m of 2m high AEGB lift, such that no more than 1m (vertically) of AEGB is unconfined at any one time.*

4.0 ASSESSMENT

4.1.1 The assessments are presented in the order analysed.

4.2 Liner Construction and Waste Stability Assessment

Critical Slopes and Factors of Safety

4.2.1 **Table SRA11**, **Table SRA12**, **Table SRA13** and **Table SRA14** highlight the factors of safety recorded for the stability analysis of the quarry lining system construction / waste buttressing phases. The PLAXIS printouts from the stability analysis (printouts presented for every 5th lift of the construction / waste buttressing), showing the critical failure surfaces and factors of safety, are presented in **Appendix SRA2**.

4.2.2 The stability models for the 1st and 2nd years of lining system construction / waste infilling (Lifts 1-23) were run with the construction of the AEGB in 2m high lifts, with each lift being confined by waste prior to construction of the next lift. The critical failure surface from these stability analyses generally occurs in the low temporary waste slopes (2m high) modelled within the waste mass adjacent to the lining system, rather than in the AEGB itself. The lowest factor of safety for the failure surfaces in the temporary waste slopes is FOS=1.197, which occurs during the 5th lining system lift. This is just below the minimum required FOS=1.2 for temporary waste slopes. This is discussed in the section below. All the other failure surfaces in the temporary waste slopes pass the FOS=1.2 requirement. For the failure surfaces which occur through the liner lifts, all the factors of safety meet the minimum required FOS=1.3, with the lowest factor of safety being for Liner Lift 16 (FOS=1.306). The stability of the AEGB construction for these models is therefore deemed to be acceptable. For the waste buttressing phases, as the liner slopes / temporary waste slopes are confined, the critical failure surfaces generally occur in the existing rock face of the quarry, with very high factors of safety; the existing face is deemed to be stable.

4.2.3 The stability models for the 3rd-5th years, and final years, of the lining construction / waste infilling (Lifts 24-50), were run with the construction of the AEGB in 2m high lifts, but with each lift being confined with waste during its construction, such that no more than a 1m of vertical height of AEGB was unconfined at any time. This was required in the modelling to prevent slope instability in the liner lifts. With this methodology in place, the critical failure surfaces for the liner lifts (with the lowest factors of safety) occur in the 2m high temporary waste flanks. All the factors of safety are well above the required FOS=1.2 (for temporary waste flanks), with the exception being for the final lift (Liner Lift 50) for which the FOS was lower at 1.181. This was due to this temporary waste flank being modelled at 2.5m high (to achieve the final level), rather than 2m high as per the proposed design. The proposed restrictions on temporary waste flank height / gradient are detailed below. For the waste buttressing phases, during which the construction of the upper 1m of the 2m AEGB lifts was modelled, along with the buttressing of the lower 1m of AEGB, the critical failure surfaces are generally in the top 1m of the liner lift. The lowest factor of safety for the waste buttressing / upper 1m of AEGB construction phases occurred for Liner Lift 50, with a value of FOS=1.412. All the factors of safety for the lining lifts where the failure surfaces are through the AEGB are above the minimum required FOS=1.3; the stability of the AEGB construction for these models is therefore deemed to be acceptable.

4.2.4 Generally, the quarry faces and side-slope lining system of the 3rd-5th years and final years models are steeper than those of the 1st and 2nd year models. The increased gradient of the slopes in the models for construction higher up in the quarry lead to the requirement in the modelling to confine the 2m high AEGB lifts with waste during their construction in order to maintain stability. The build-up of excess pore water pressures in the low permeability lining material also reduces the stability of the liner lifts and limits the height of AEGB which may be safely constructed prior to confining the slope with waste. These excess pore water pressures limit the increase of effective stress (strength) in the soil in the short-term, reducing the stability of the slope, until these pore pressures start to dissipate.

Implications for Construction / Waste Infilling

4.2.5 Considering the results detailed above, the limit to the lift height of the AEGB construction should be kept at 2m, and a limiting slope angle should be set, beyond which the 2m high lifts will require confinement during their construction, to ensure that the stability of the side-slope lining system is maintained. Based on the results and various slope angles used in the models, it is proposed that for lining against quarry faces steeper than **60° (1 in 0.58), AEGB lifts should be confined with waste during construction such that no more than 1m (vertically) of AEGB is left unconfined at any time**. For quarry faces slacker than 60°, the 2m lift height may be constructed before confining with waste, but the AEGB lifts must still be confined with waste prior to construction of the next lift. It should be noted that based on the contours shown in **Drawing AI1009/01/01**, most of the faces in Croft Quarry are steeper than 60°, and therefore most of the 2m high AEGB lifts will require confining with waste during their construction.

4.2.6 Generally, the modelling in this SRA has showed that stability of the 2m high temporary waste flanks (at a gradient of 1 in 2) modelled will be maintained, with the exception of one waste tipping phase where the factor of safety was just below the minimum required FOS=1.2. Due to this reported factor of safety being below the required FOS=1.2, it is recommended that the temporary waste flanks are tipped at a **gradient of 1 in 2.5 at 2m high**, rather than a gradient of 1 in 2 at 2m high, to ensure that an acceptable factor of safety, and therefore stability, will be maintained for all temporary waste flanks. Therefore, the proposed strategy of placing waste in the middle of the quarry and leaving a lower bench / rock trap close to the perimeter, adjacent to the top of the side-slope lining system, is deemed to be acceptable. Temporary waste slopes should not be tipped to steeper than **1 in 2.5** or higher than **2m** (with the exception of high temporary waste flank covered in Report Reference: AI1000/07.R1, see Section 5.0 below).

4.2.7 The stability modelling has shown that the groundwater pressure behind the side-slope lining system (from gradually rising groundwater levels in the bedrock as the quarry is infilled) is not driving instability within the AEGB. This is clear from the printouts in **Appendix SRA2** which show critical failure surfaces occurring within the liner lifts rather than passing through them with the failure coming from behind. It should be noted that this has only been shown through modelling for a 2m high AEGB lift construction; if higher lifts where constructed the impact of groundwater may be more significant.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1.1 This Stability Risk Assessment (SRA) has addressed the stability issues pertaining to the proposed quarry lining system construction, and infilling of waste, at Croft Quarry. This SRA has been prepared as part of the application to vary Environmental Permit EPR/EB3708GW to add a Deposit for Recovery activity to support restoration of Croft Quarry. Analyses have been based on the available site investigation information, conservative materials parameters, and a worst-case interpretation.

5.1.2 The stability assessments undertaken have shown that the stability of the quarry lining system construction and waste infilling is likely to be maintained if the following restrictions on construction are followed:

- The quarry lining system (AEGB) must be constructed in 2m high lifts (not higher), with each lift being buttressed with waste as the quarry is infilled, prior to the construction of the lift above;
- The waste infill must be placed in layers across the quarry in conjunction with the AEGB construction, temporary waste flanks shall not exceed 2m high, or a gradient of 1 in 2.5;
- The infill in the middle of the quarry may be placed up to 2m higher than the lining system, as long as a lower bench is left near the edge of the lining system at the same level as top of the AEGB construction; and
- Where the gradient of the lining system will be steeper than **60° (1 in 0.58)**, the 2m high lifts shall be buttressed with waste during their construction, such that no more than a 1m height of AEGB is unconfined at any time.

5.1.3 If the restrictions outlined above are not followed during construction, then stability failures in the AEGB construction / waste slopes may occur. The proposed lining system construction details are shown on **Drawing AI1009/14/14.**

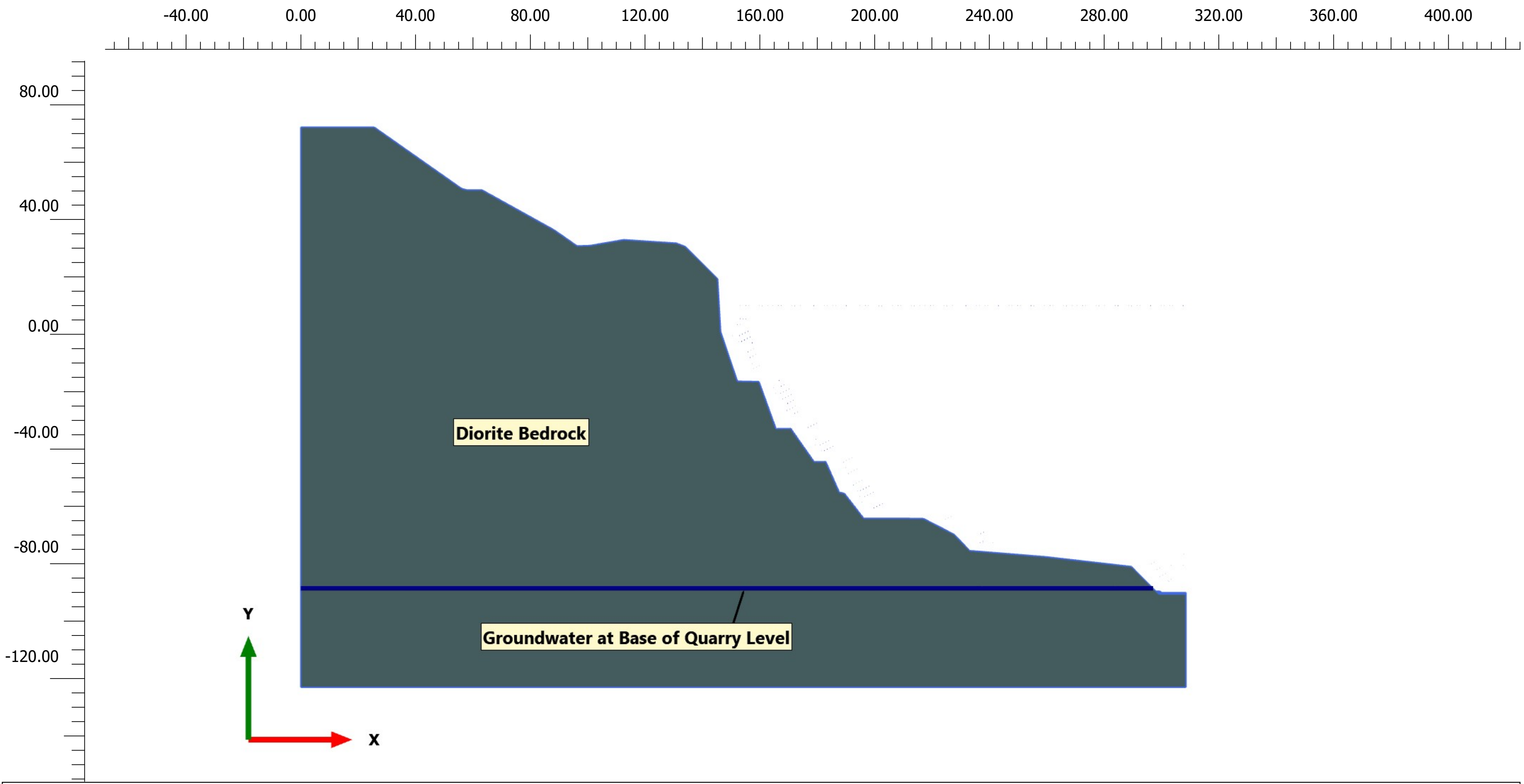
5.1.4 There is some risk of loose rock falling into the construction area from the quarry faces above. To mitigate this risk, it is proposed that the area immediately adjacent to the lining system (the lower bench in the waste modelled in this SRA) will be used as a rock trap to contain any falling material. The use of remote-controlled or reinforced armoured compaction plant for the AEGB should also be considered, to avoid the requirement for construction workers in the area immediately below the rock faces. A pedestrian exclusion zone should be maintained. Risk mitigation measures shall be put in place in line with the quarry regulations and AI's safe methods of work.

5.1.5 Report reference: AI1000/07.R1 details the stability risk assessment undertaken for a higher temporary waste flank, which may be formed from the proposed eastern extension area across the main quarry area to the western quarry highwall, if the extension area is excavated. To achieve stability for this temporary waste flank, the slope shall be formed over ~6.5 years (maximum waste infilling rate of 750,000m^3 per year), with the waste slope gradient limited to 1 in 5, including 2 horizontal benches (6-10m wide), to achieve a final waste height of 9mAOD.

5.1.6 Should the material types or liner construction / waste infilling speeds significantly change from those modelled in this SRA, then further assessments will be required to ensure that the stability of the AEGB / waste will be maintained.

APPENDIX SRA1
PLAXIS Model Geometry and Material Parameters

Output Version 21.1.0.479

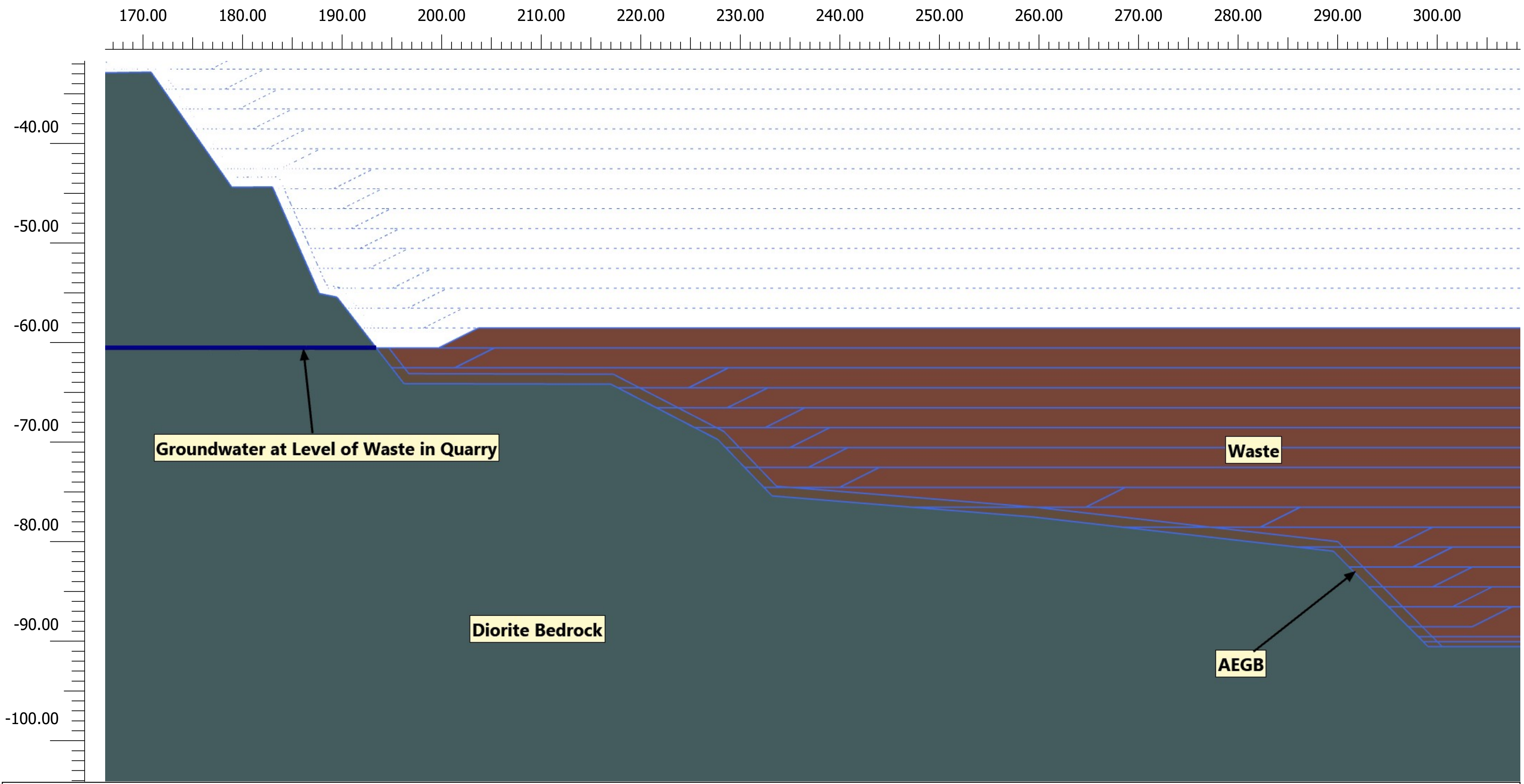


Model Geometry - Prior to Quarry Infilling

Project description		Date
Croft Quarry Infill		13/03/2024
Project filename	Step	Company
Croft Quarry Infill 2024 Mode ...	4	Sirius Environmental Ltd

sirius Environmental

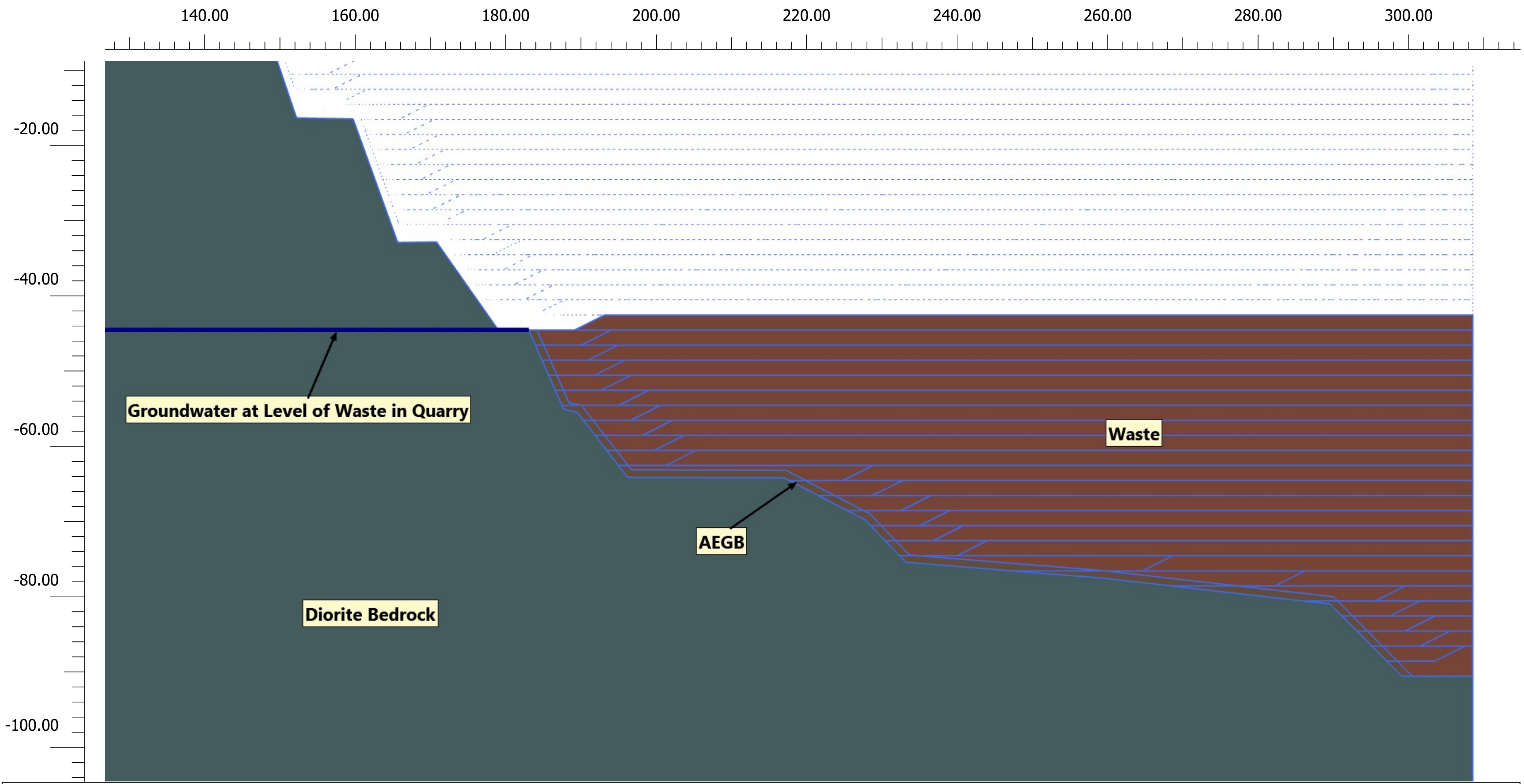
Output Version 21.1.0.479



Model Geometry - End of 1st Year of Infilling

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 217	*Company* Sirius Environmental Ltd

Output Version 21.1.0.479

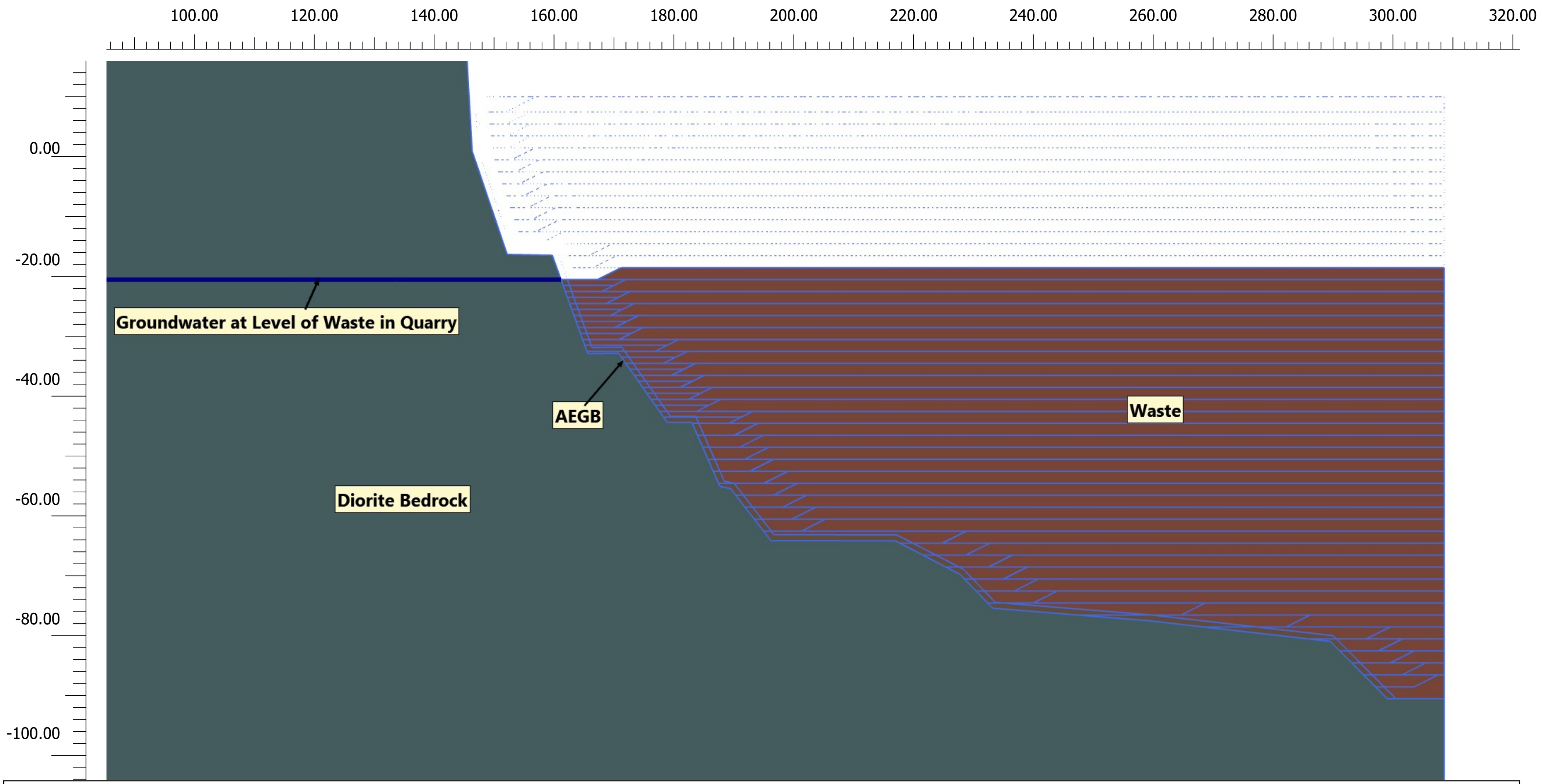


Model Geometry - End of 2nd Year of Infilling

Project description		Date
Croft Quarry Infill		13/03/2024

Project filename	Step	Company
Croft Quarry Infill 2024 Mode ...	183	Sirius Environmental Ltd

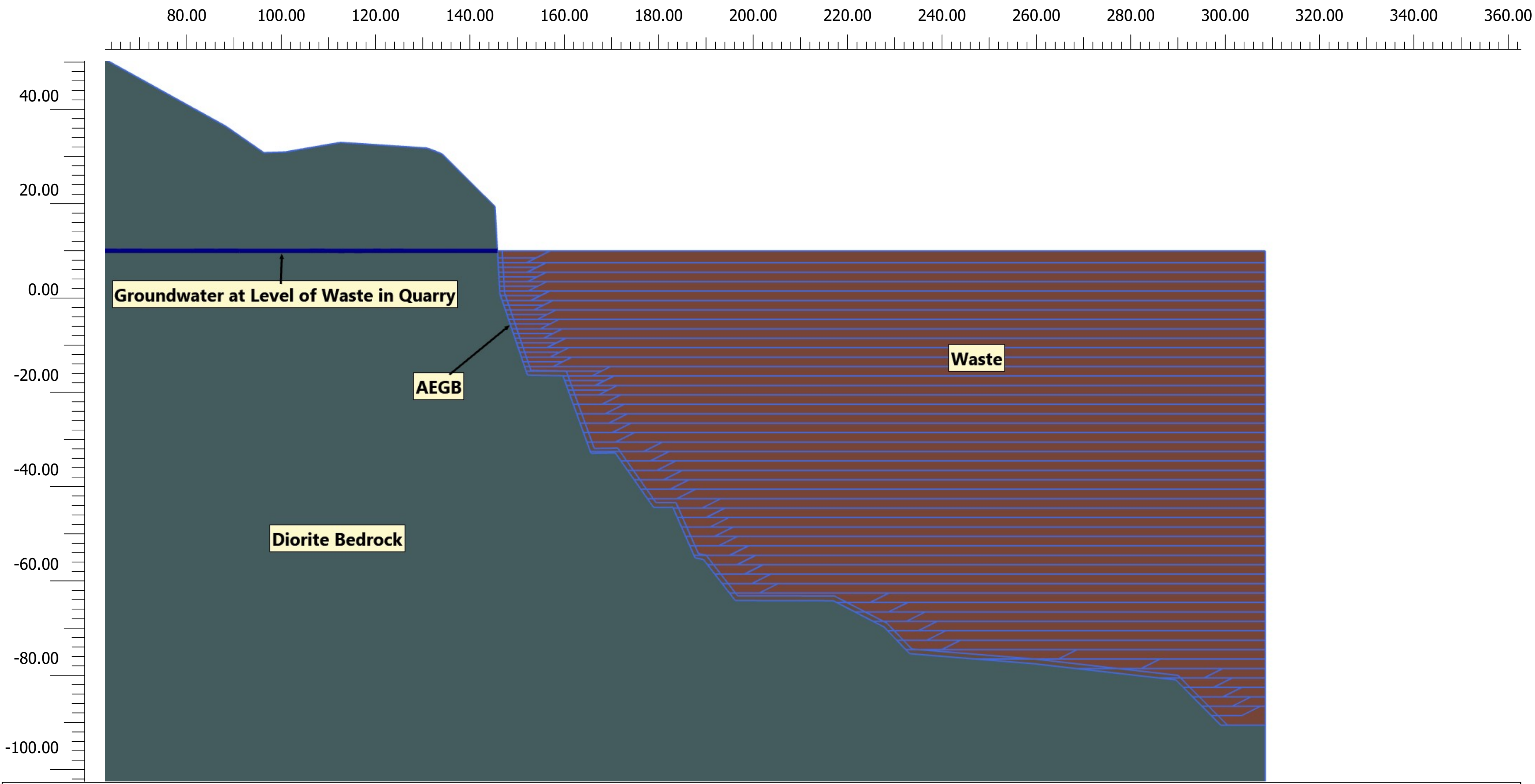
Output Version 21.1.0.479



Model Geometry - End of 5th Year of Infilling

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 233	*Company* Sirius Environmental Ltd

Output Version 21.1.0.479



Model Geometry - End of Waste Infilling

Project description Croft Quarry Infill			*Date* 13/03/2024
Project filename Croft Quarry Infill 2024 Mode ...	*Step* 324	*Company* Sirius Environmental Ltd	

Material set			
Identification number		2	3
Identification		AEGB	Infill
Material model		Hardening soil	Hardening soil
Drainage type		Undrained (A)	Undrained (A)
Colour		RGB 95, 73, 58	RGB 114, 67, 54
Comments			
General properties			
γ_{unsat}	kN/m³	19.00	19.00
γ_{sat}	kN/m³	20.00	20.00
Advanced			
Void ratio			
Dilatancy cut-off		No	No
e_{init}		0.5000	0.5000
e_{min}		0.000	0.000
e_{max}		999.0	999.0
Stiffness			
$E_{50}{}^{ref}$	kN/m²	6000	4000
$E_{oed}{}^{ref}$	kN/m²	6000	4000
$E_{ur}{}^{ref}$	kN/m²	18.00E3	12.00E3
power (m)		0.7500	0.7500
Alternatives			
Use alternatives		No	No
C_c		0.05750	0.08625
C_s		0.01725	0.02587
e_{init}		0.5000	0.5000
Strength			
c_{ref}	kN/m²	5.000	5.000
φ (phi)	°	25.00	25.00
ψ (psi)	°	0.000	0.000

Identification		AEGB	Infill
Advanced			
Set to default values		Yes	Yes
Stiffness			
ν_{ur}		0.2000	0.2000
p_{ref}	kN/m²	100.0	100.0
K_0^{nc}		0.5774	0.5774
Strength			
c_{inc}	kN/m²/m	0.000	0.000
y_{ref}	m	0.000	0.000
R_f		0.9000	0.9000
Tension cut-off		Yes	Yes
Tensile strength	kN/m²	0.000	0.000
Undrained behaviour			
Undrained behaviour		Standard	Standard
Skempton-B		0.9866	0.9866
ν_u		0.4950	0.4950
$K_{w,ref}$ / n	kN/m²	737.5E3	491.7E3
Stiffness			
Stiffness		Standard	Standard
Strength			
Strength		Rigid	Rigid
R_{inter}		1.000	1.000
Consider gap closure		Yes	Yes
Real interface thickness			
δ_{inter}		0.000	0.000
Groundwater			
Cross permeability		Impermeable	Impermeable
Drainage conductivity, dk	m³/day/m	0.000	0.000
Thermal			
R	m² K/kW	0.000	0.000

Identification		AEGB	Infill
K0 settings			
K_0 determination		Automatic	Automatic
$K_{0,x} = K_{0,z}$		Yes	Yes
$K_{0,x}$		0.5774	0.5774
$K_{0,z}$		0.5774	0.5774
Overconsolidation			
OCR		1.000	1.000
POP	kN/m²	0.000	0.000
Model			
Data set		Standard	Standard
Soil			
Type		Coarse	Coarse
< 2 μm	%	10.00	10.00
2 μm - 50 μm	%	13.00	13.00
50 μm - 2 mm	%	77.00	77.00
Flow parameters			
Use defaults		None	None
k_x	m/day	0.4320E-3	0.4320E-3
k_y	m/day	0.4320E-3	0.4320E-3
$-\psi_{unsat}$	m	10.00E3	10.00E3
e_{init}		0.5000	0.5000
S_s	1/m	0.000	0.000
Change of permeability			
c_k		1000E12	1000E12

Identification		AEGB	Infill
Parameters			
c_s	kJ/t/K	0.000	0.000
λ_s	kW/m/K	0.000	0.000
ρ_s	t/m³	0.000	0.000
Solid thermal expansion		Volumetric	Volumetric
α_s	1/K	0.000	0.000
D_v	m²/day	0.000	0.000
f_{Tv}		0.000	0.000
Unfrozen water content		None	None

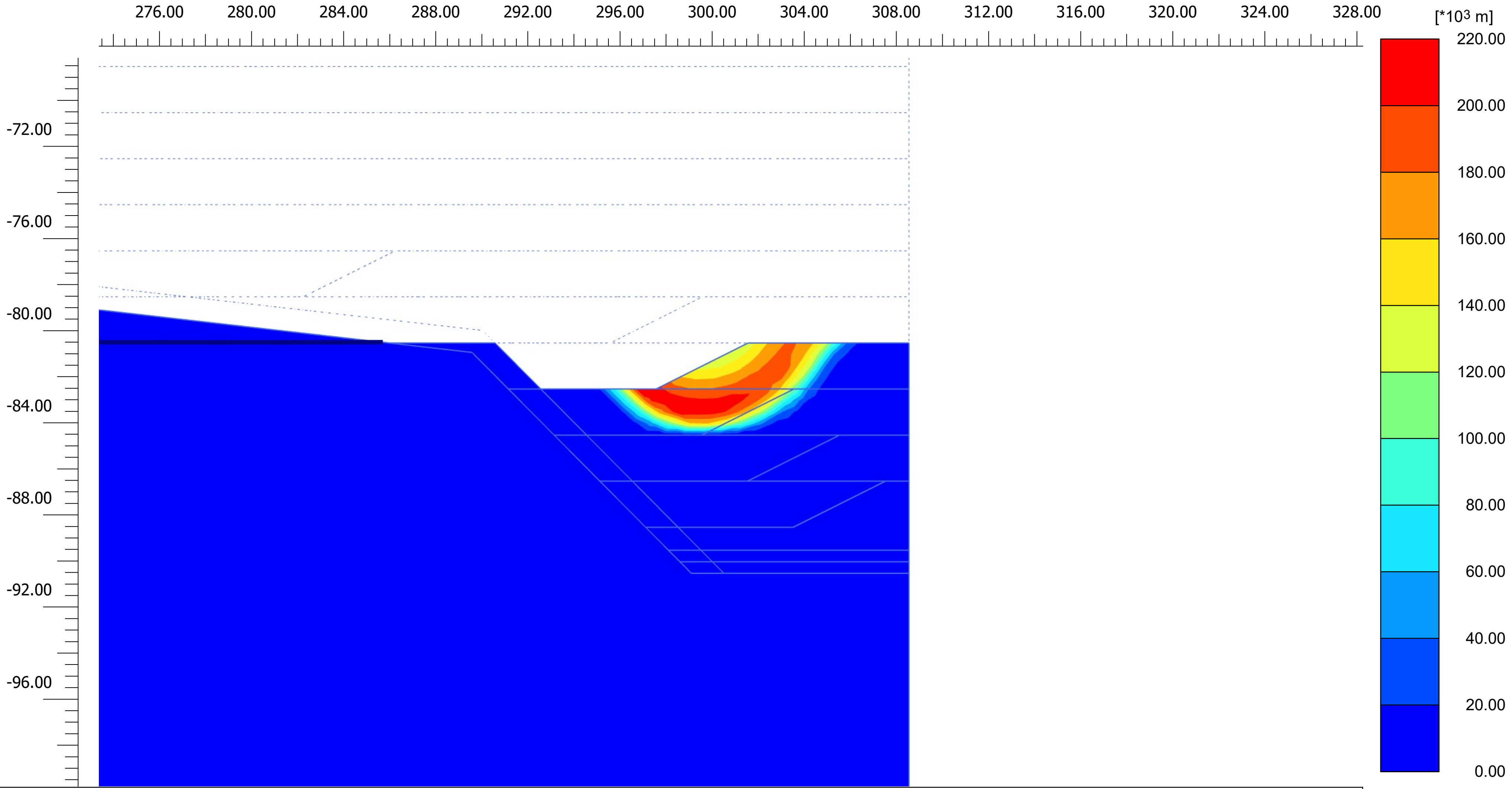
Material set		
Identification number		1
Identification		Bedrock
Material model		Hoek-Brown
Drainage type		Drained
Colour		RGB 67, 89, 91
Comments		
General properties		
γ_{unsat}	kN/m³	28.00
γ_{sat}	kN/m³	29.00
Advanced		
Void ratio		
Dilatancy cut-off		No
e_{init}		0.5000
e_{min}		0.000
e_{max}		999.0
Stiffness		
E'_{rm}	kN/m²	500.0E3
ν (nu)		0.3000
Hoek-Brown parameters		
$\|\sigma_{ci}\|$	kN/m²	175.0E3
m_i		25.00
GSI		60.00
D		1.000
Hoek-Brown criterion		
m_b		1.436
s		1.273E-3
a		0.5028
Rock mass parameters		
σ_t	kN/m²	155.1
σ_c	kN/m²	-6126
Dilatancy angle		
ψ_{max}	°	0.000
σ_{ψ}	kN/m²	0.000

Identification		Bedrock
Advanced		
Undrained behaviour		
Undrained behaviour		Standard
Stiffness		
Stiffness		Standard
Strength		
Strength		Rigid
R_{inter}		1.000
Consider gap closure		Yes
Real interface thickness		
δ_{inter}		0.000
Groundwater		
Cross permeability		Impermeable
Drainage conductivity, dk	$m^3/day/m$	0.000
Thermal		
R	m^2 K/kW	0.000
K0 settings		
K_0 determination		Automatic
$K_{0,x} = K_{0,z}$		Yes
$K_{0,x}$		0.5000
$K_{0,z}$		0.5000
Model		
Data set		Standard
Soil		
Type		Coarse
< 2 μm	%	10.00
2 μm - 50 μm	%	13.00
50 μm - 2 mm	%	77.00

Identification		Bedrock
Flow parameters		
Use defaults		None
k_x	m/day	8.640
k_y	m/day	8.640
$-\psi_{unsat}$	m	10.00E3
e_{init}		0.5000
Change of permeability		
c_k		1000E12
Parameters		
c_s	kJ/t/K	0.000
λ_s	kW/m/K	0.000
ρ_s	t/m³	0.000
Solid thermal expansion		Volumetric
α_s	1/K	0.000
D_v	m²/day	0.000
f_{Tv}		0.000
Unfrozen water content		None

APPENDIX SRA2
PLAXIS Stability Printouts

Output Version 21.1.0.479



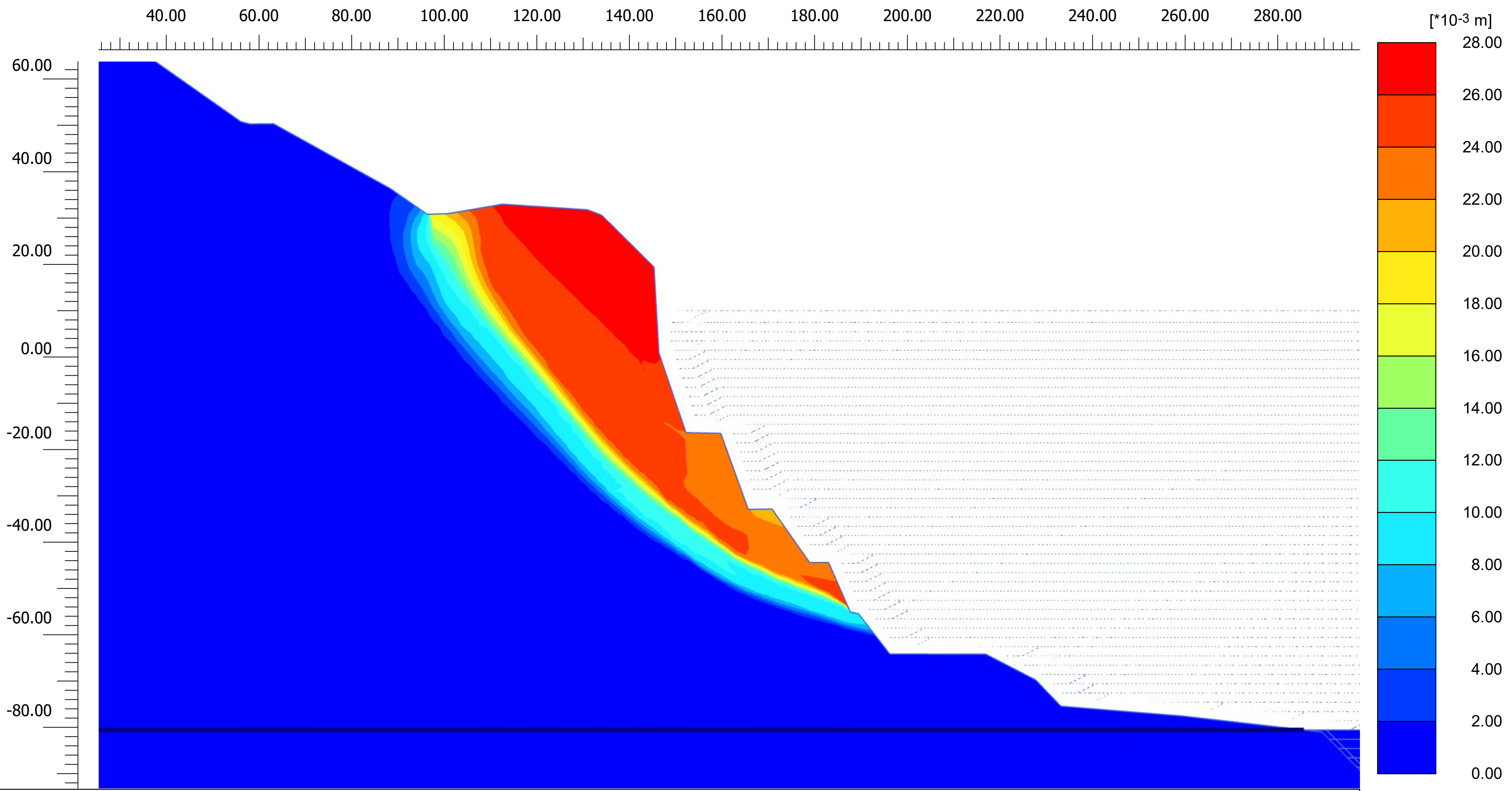
Incremental displacements |Δu| (scaled up $0.0500*10^{-3}$ times)

Maximum value = $218.0*10^{3}$ m (Element 5659 at Node 27057)

Project description		Date
Croft Quarry Infill		13/03/2024
Project filename	Step	Company
Croft Quarry Infill 2024 Mode ...	2456	Sirius Environmental Ltd

Step info				
Phase	ECL5S [Phase_25]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	-1.148E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.3627E-3	ΣM_{sf}	1.197
Time	Increment	0.000	End time	103.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.7480
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	164.1 kN/m^2			

Output Version 21.1.0.479



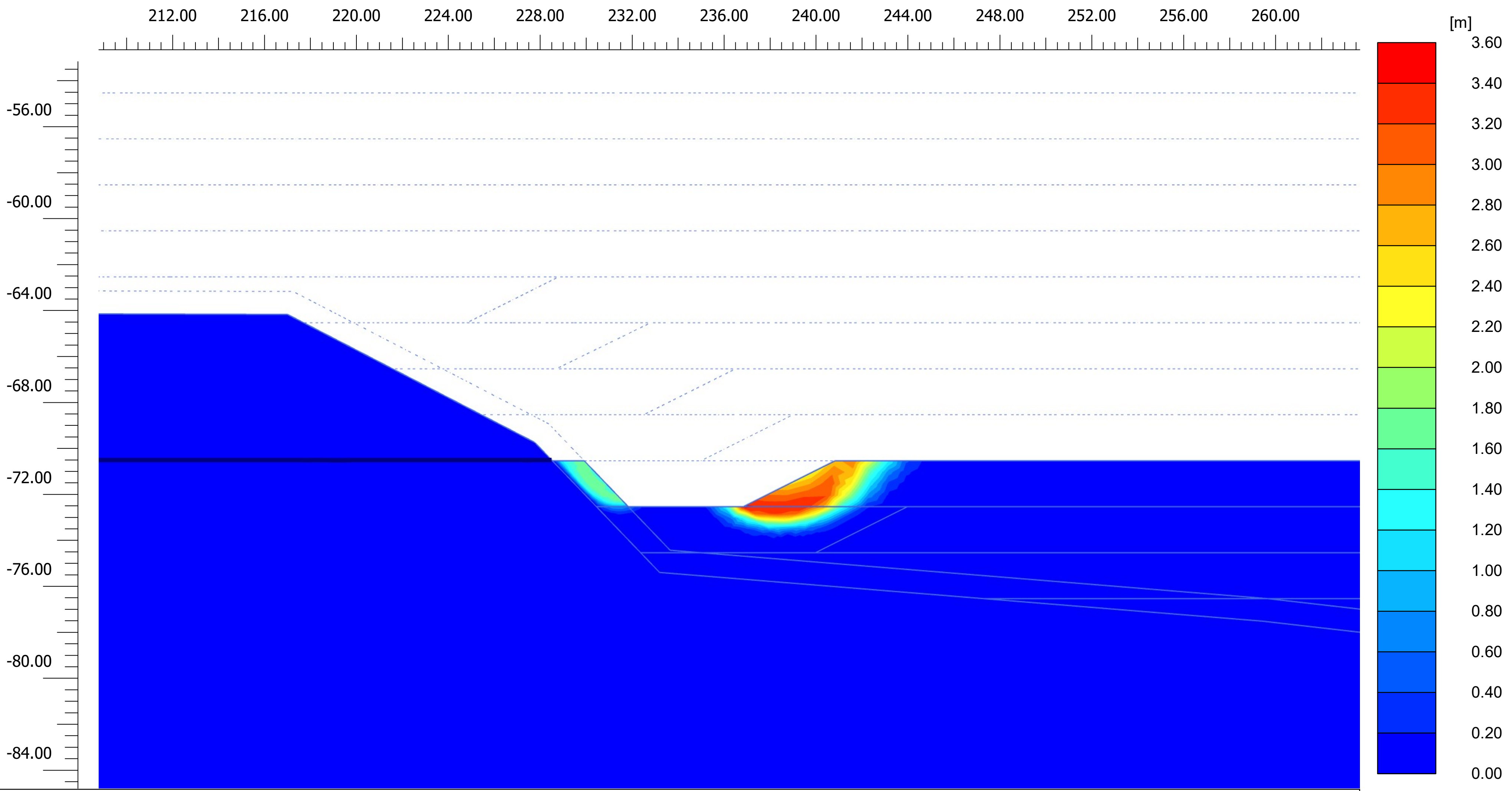
Incremental displacements |Δu| (scaled up 500 times)

Maximum value = 0.02695 m (Element 3506 at Node 2243)

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 1956	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL5BS [Phase_26]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.7812E-3			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	5.000E-3	ΣM_{sf}	4.081
Time	Increment	0.000	End time	104.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.7484
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	122.8 kN/m^2			

Output Version 21.1.0.479



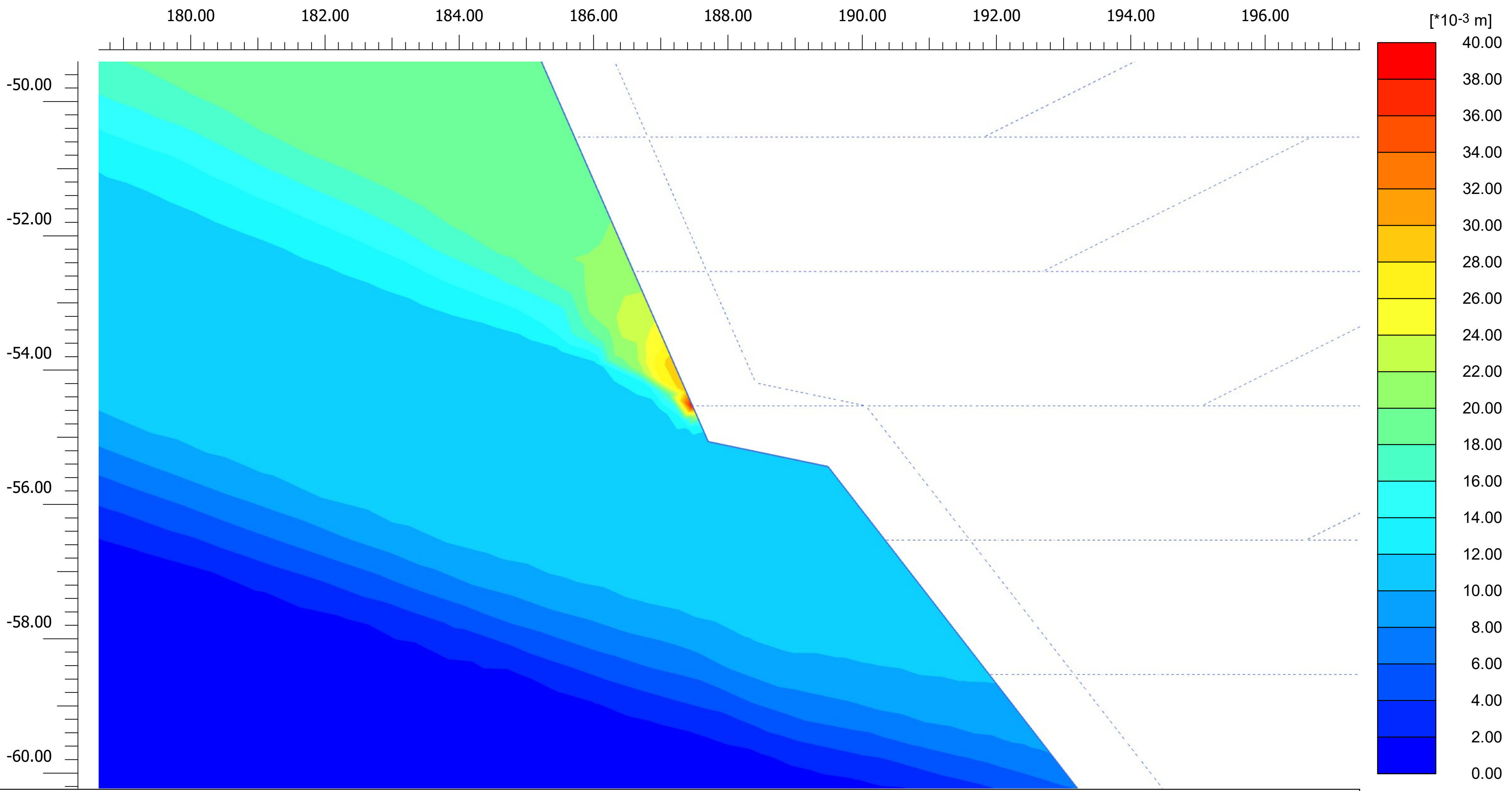
Incremental displacements |Δu| (scaled up 5.00 times)

Maximum value = 3.470 m (Element 5249 at Node 24233)

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 767	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL10S [Phase_66]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	8.483E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.1496E-3	ΣM_{sf}	1.414
Time	Increment	0.000	End time	223.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.7613
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	422.0 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 200 times)

Maximum value = 0.03889 m (Element 4266 at Node 10491)

Project description
Croft Quarry Infill

Date
13/03/2024

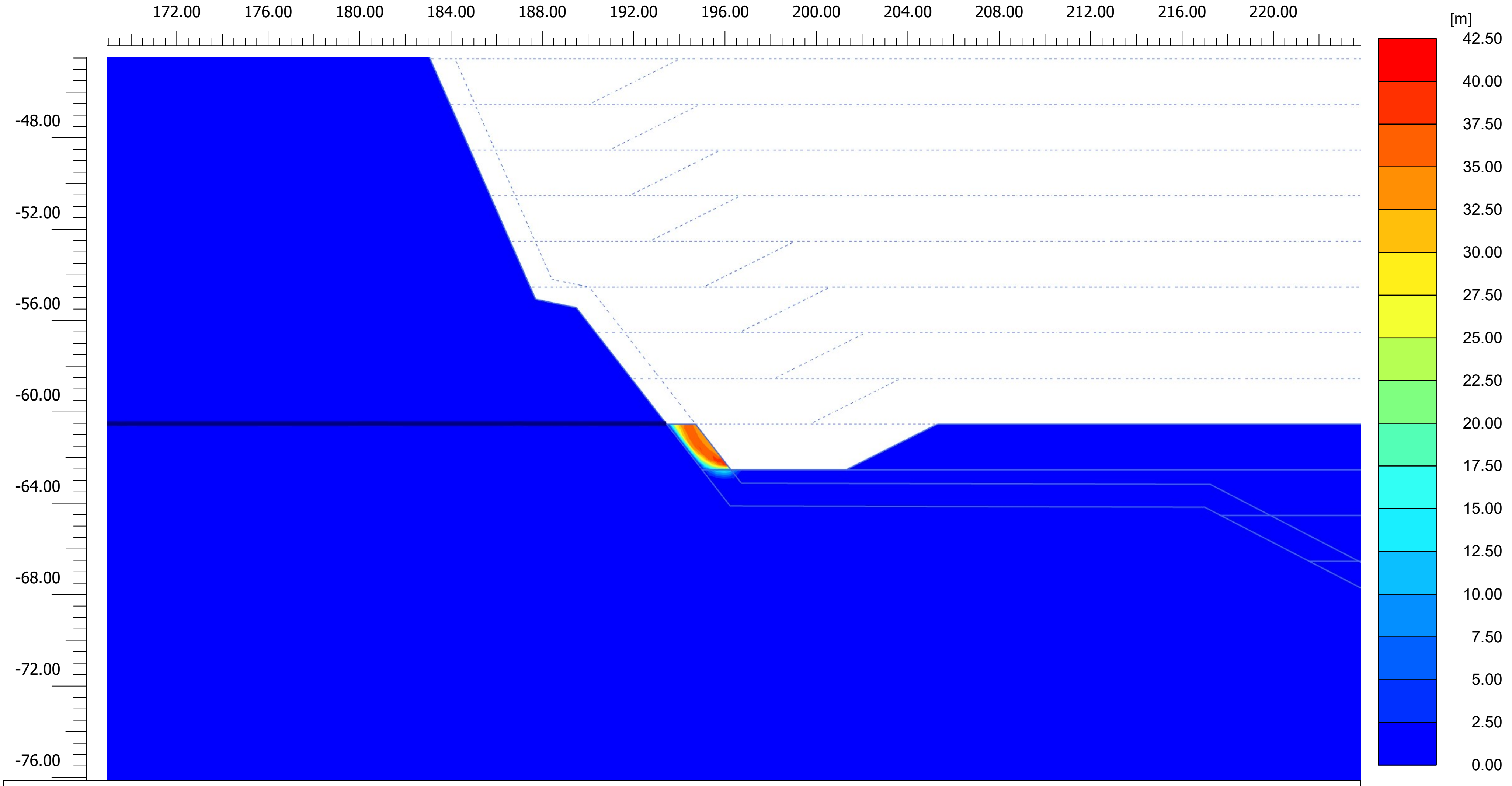
Project filename
Croft Quarry Infill 2024 Mode ...

Step
2156

Company
Sirius Environmental Ltd

Step info				
Phase	ECL10BS [Phase_67]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	1.000			
Relative stiffness	0.1617E-3			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	1.740E-3	ΣM_{sf}	4.071
Time	Increment	0.000	End time	224.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.7616
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	232.0 kN/m^2			

Output Version 21.1.0.479



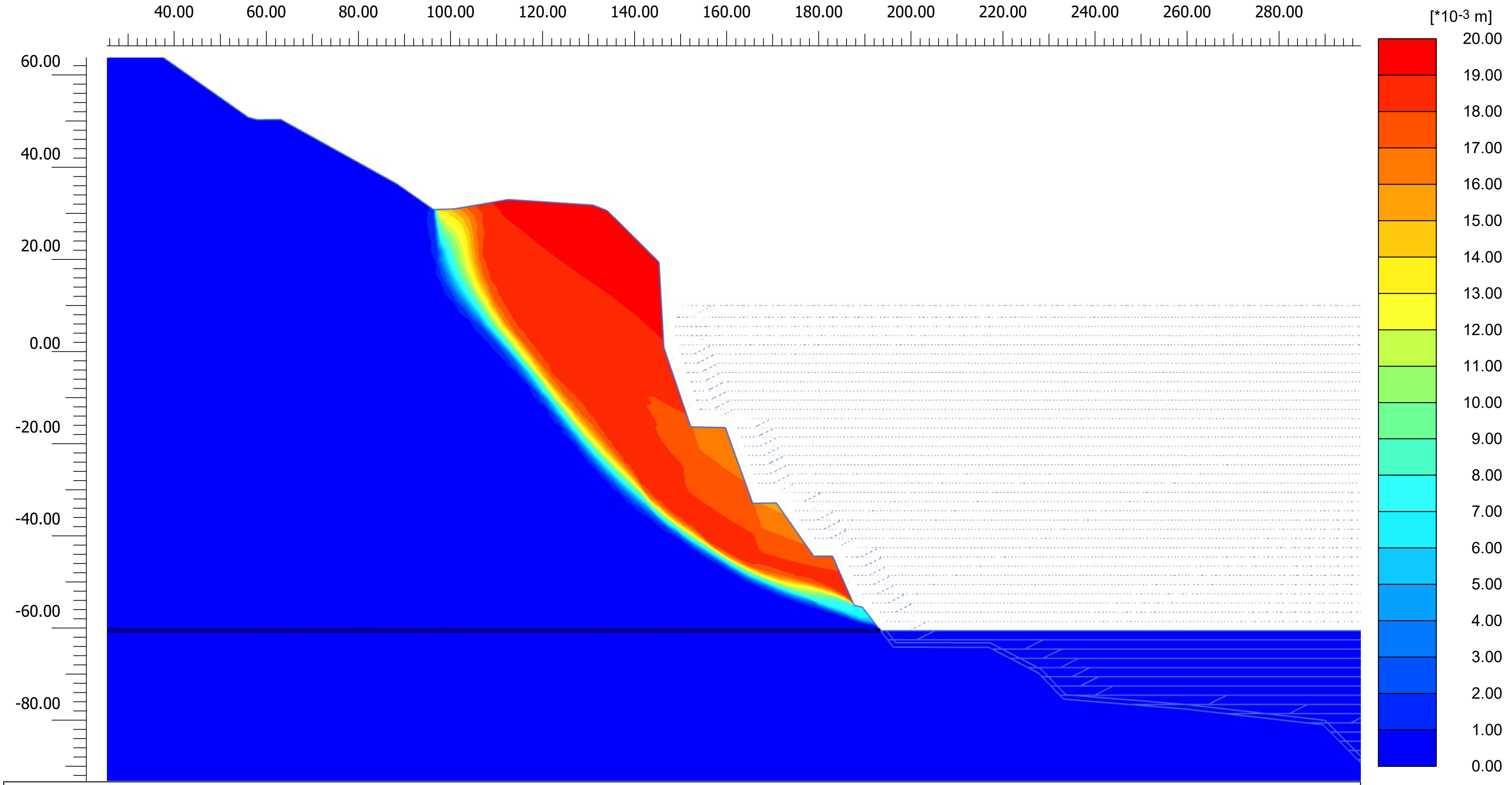
Incremental displacements |Δu| (scaled up 0.200 times)

Maximum value = 40.05 m (Element 4818 at Node 11978)

Project description Croft Quarry Infill			*Date* 13/03/2024
Project filename Croft Quarry Infill 2024 Mode ...	*Step* 267	*Company* Sirius Environmental Ltd	

Step info				
Phase	ECL15S [Phase_76]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	1.000			
Relative stiffness	0.02558E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.05371E-3	ΣM_{sf}	1.307
Time	Increment	0.000	End time	343.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.7819
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	229.5 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 500 times)

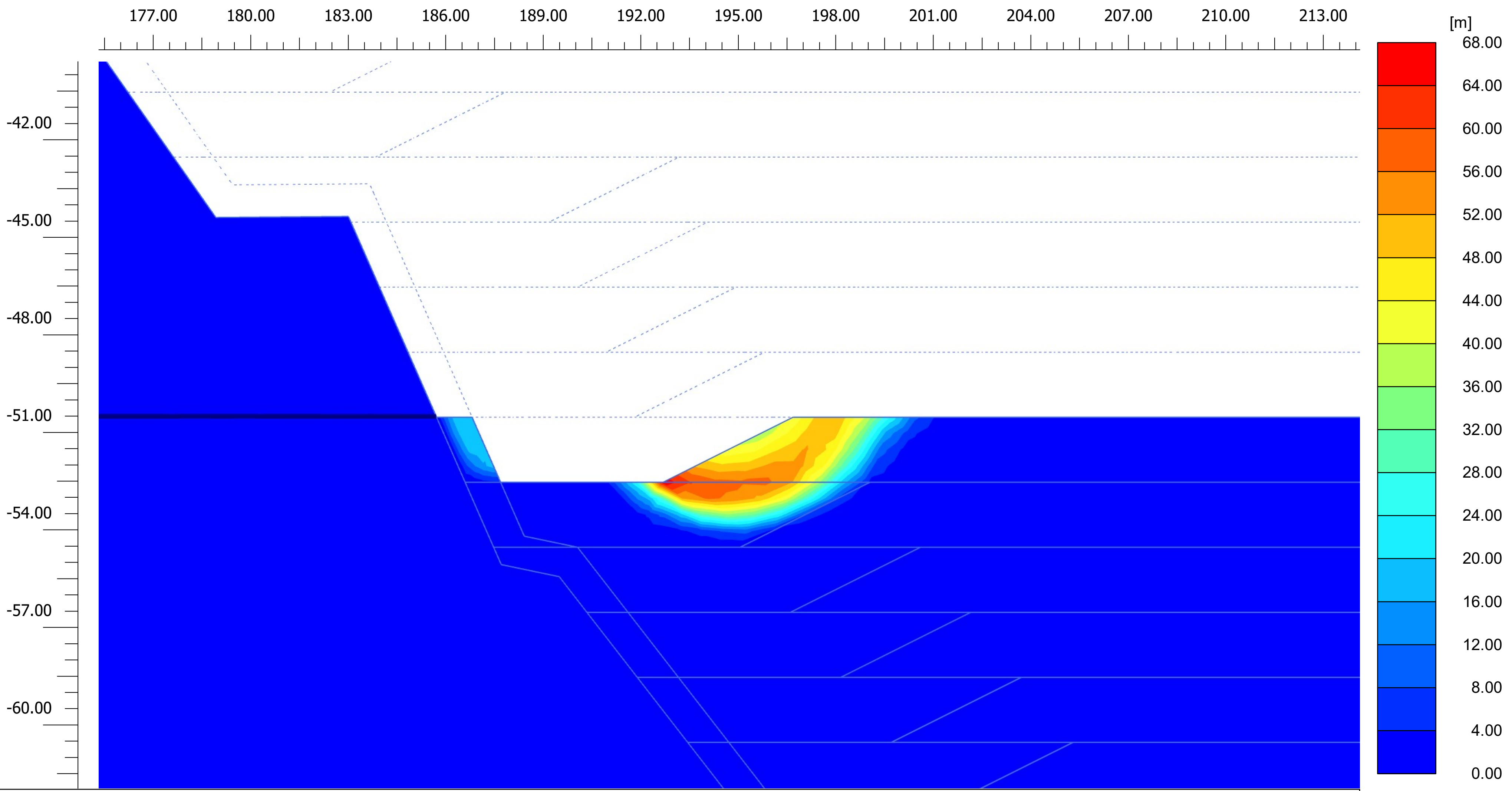
Maximum value = 0.01965 m (Element 3506 at Node 2243)

Project description	Date
Croft Quarry Infill	13/03/2024

Project filename	Step	Company
Croft Quarry Infill 2024 Mode ...	2756	Sirius Environmental Ltd

Step info				
Phase	ECL15BS [Phase_77]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.7425E-3			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.01193	ΣM_{sf}	4.027
Time	Increment	0.000	End time	344.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.7822
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	290.9 kN/m^2			

Output Version 21.1.0.479



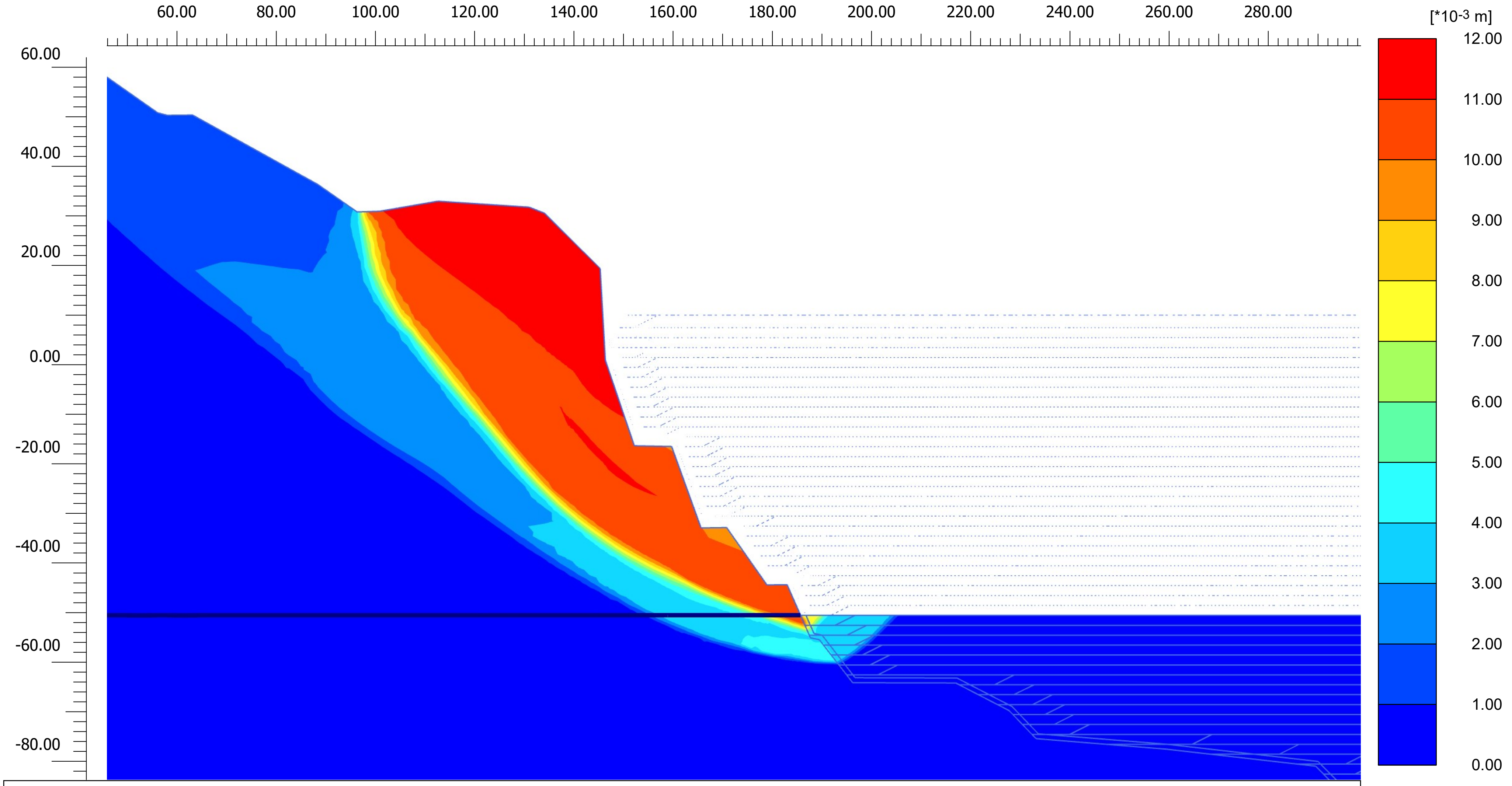
Incremental displacements |Δu| (scaled up 0.200 times)

Maximum value = 67.09 m (Element 4374 at Node 14645)

Project description Croft Quarry Infill			*Date* 13/03/2024
Project filename Croft Quarry Infill 2024 Mode ...	*Step* 614	*Company* Sirius Environmental Ltd	

Step info				
Phase	ECL20S [Phase_25]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	1.000			
Relative stiffness	0.5856E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-1.866E-3	ΣM_{sf}	1.327
Time	Increment	0.000	End time	182.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8075
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	132.4 kN/m^2			

Output Version 21.1.0.479



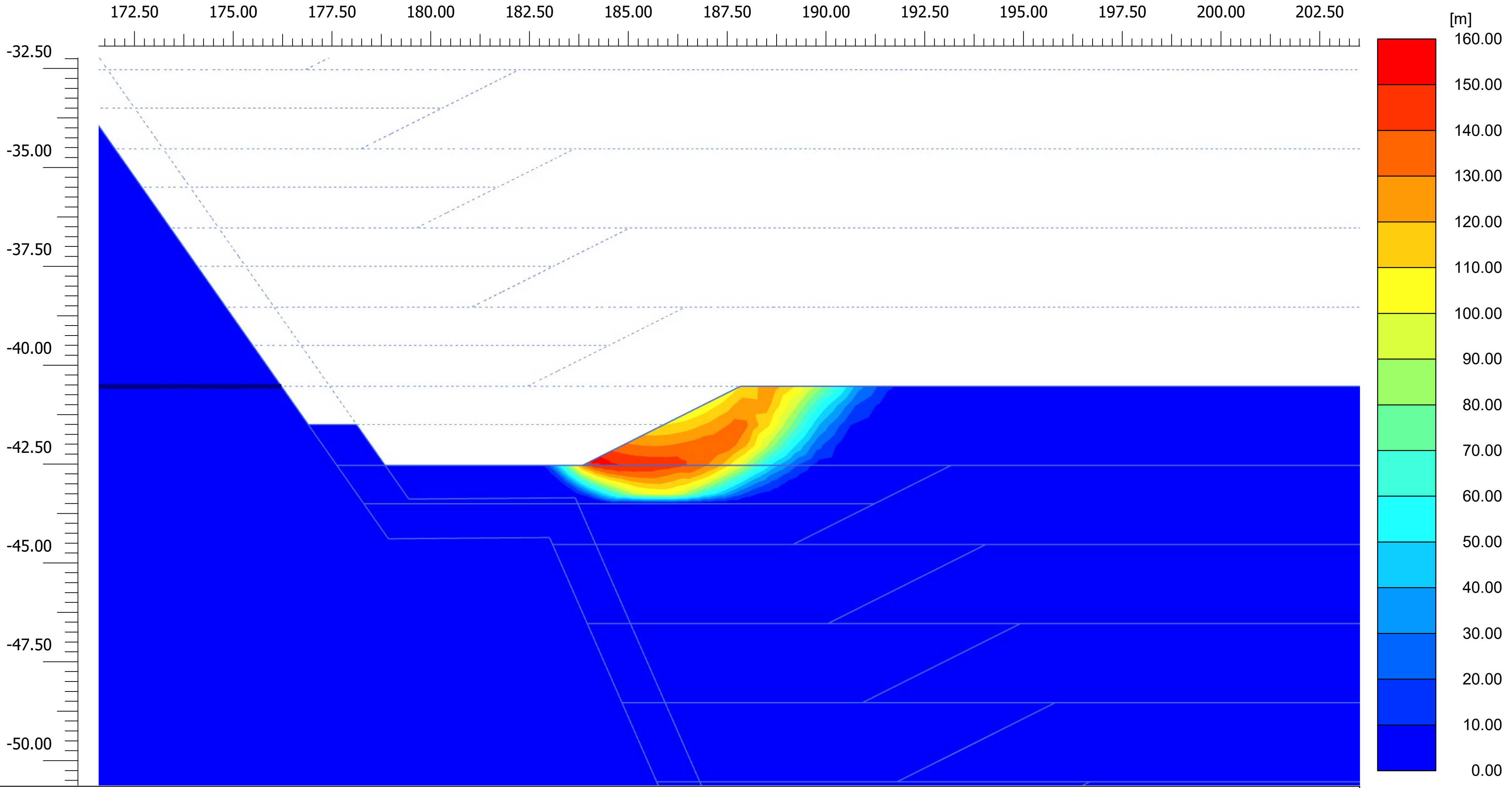
Incremental displacements |Δu| (scaled up 500 times)

Maximum value = 0.01196 m (Element 3505 at Node 3001)

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 15/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 151	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL20BS [Phase_26]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	1.026E-3			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-4.069E-3	ΣM_{sf}	4.103
Time	Increment	0.000	End time	183.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8079
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	353.7 kN/m^2			

Output Version 21.1.0.479



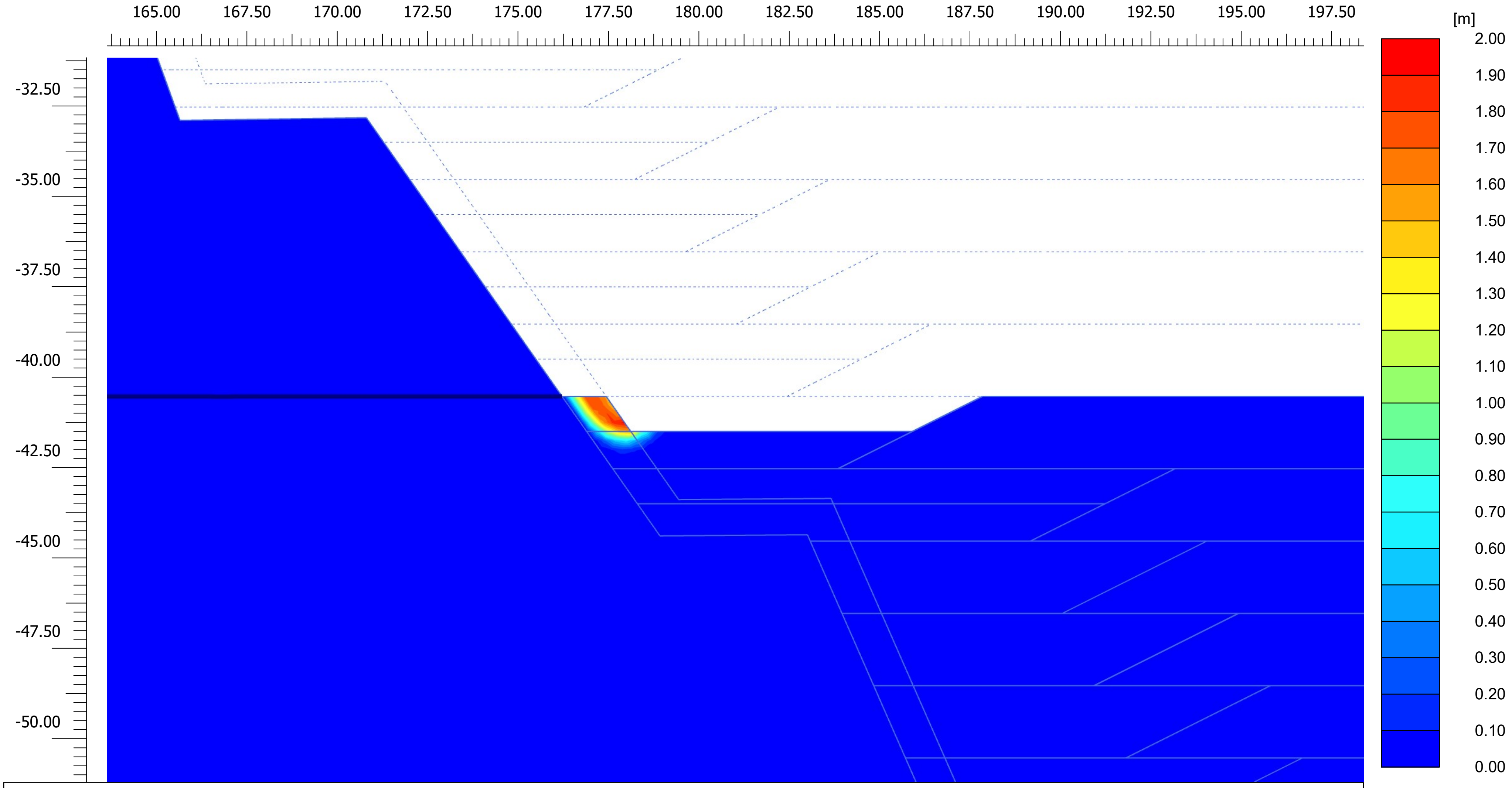
Incremental displacements |Δu| (scaled up 0.0500 times)

Maximum value = 154.6 m (Element 2997 at Node 11918)

Project description		*Date*
Croft Quarry Infill		13/03/2024
Project filename	*Step*	*Company*
Croft Quarry Infill 2024 Mode ...	1283	Sirius Environmental Ltd

Step info				
Phase	ECL25S [Phase_16]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.06863E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.7119E-3	ΣM_{sf}	1.599
Time	Increment	0.000	End time	93.00
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8348
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	232.2 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 5.00 times)

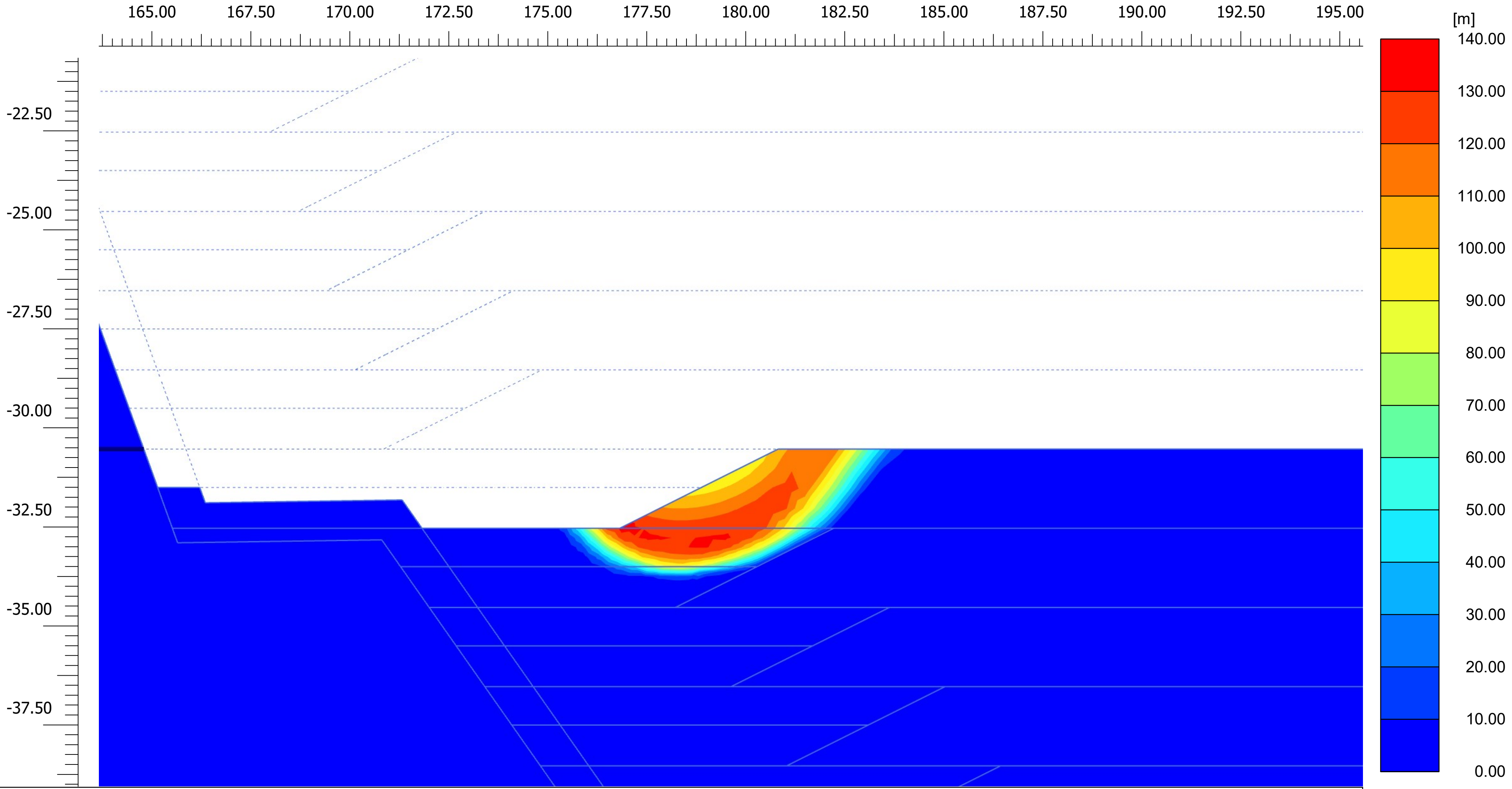
Maximum value = 1.926 m (Element 2912 at Node 8091)

Project description	Date
Croft Quarry Infill	13/03/2024

Project filename	Step	Company
Croft Quarry Infill 2024 Mode ...	1233	Sirius Environmental Ltd

Step info				
Phase	ECL25BS [Phase_17]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-0.03747E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.3325E-3	ΣM_{sf}	2.008
Time	Increment	0.000	End time	94.00
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8349
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	437.3 kN/m^2			

Output Version 21.1.0.479



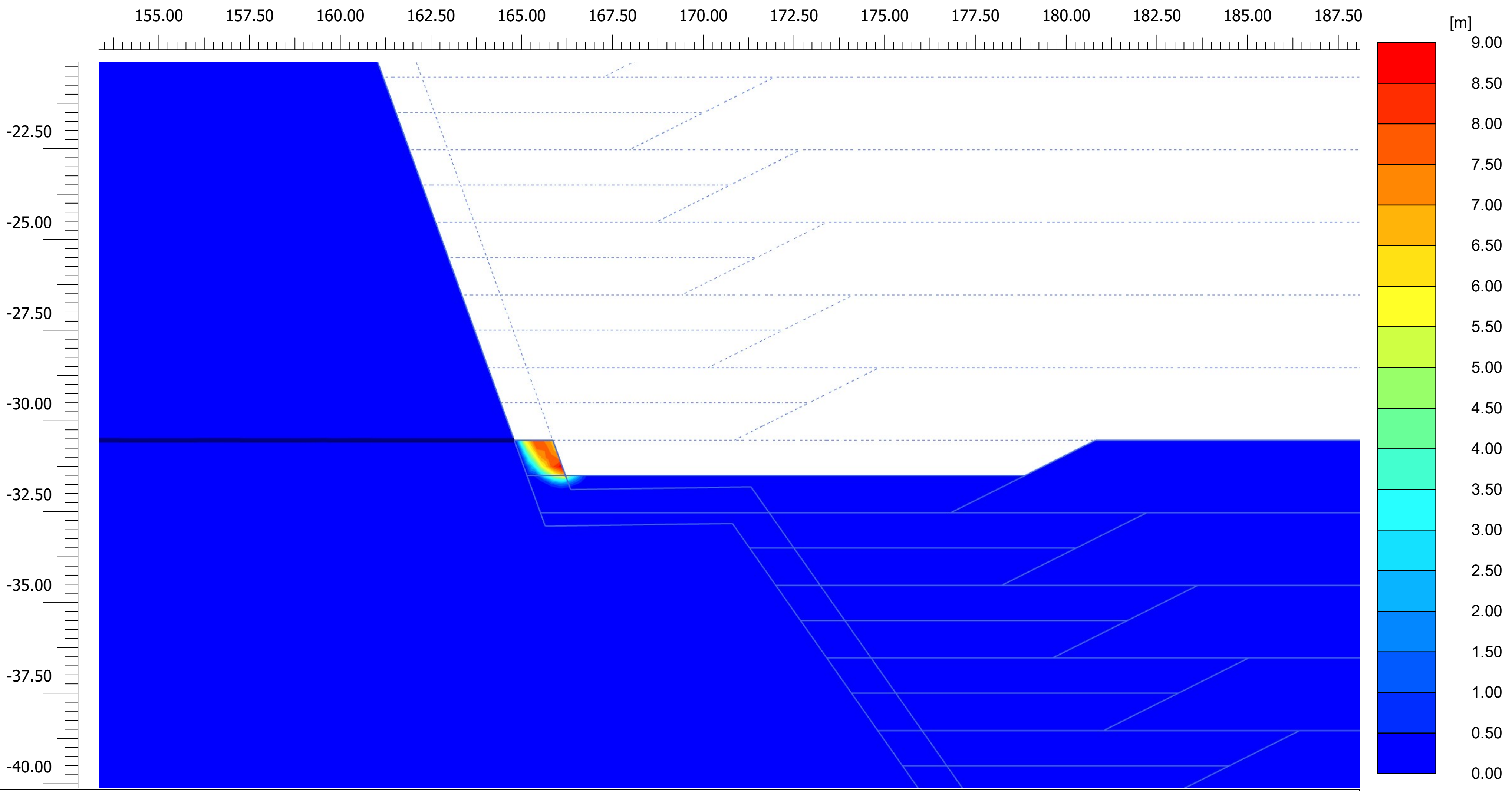
Incremental displacements |Δu| (scaled up 0.0500 times)

Maximum value = 132.5 m (Element 2396 at Node 11773)

Project description			*Date*
Croft Quarry Infill			13/03/2024
Project filename	*Step*	*Company*	
Croft Quarry Infill 2024 Mode ...	833	Sirius Environmental Ltd	

Step info				
Phase	ECL30S [Phase_60]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.02880E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	1.927E-3	ΣM_{sf}	1.436
Time	Increment	0.000	End time	548.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8641
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	358.4 kN/m^2			

Output Version 21.1.0.479



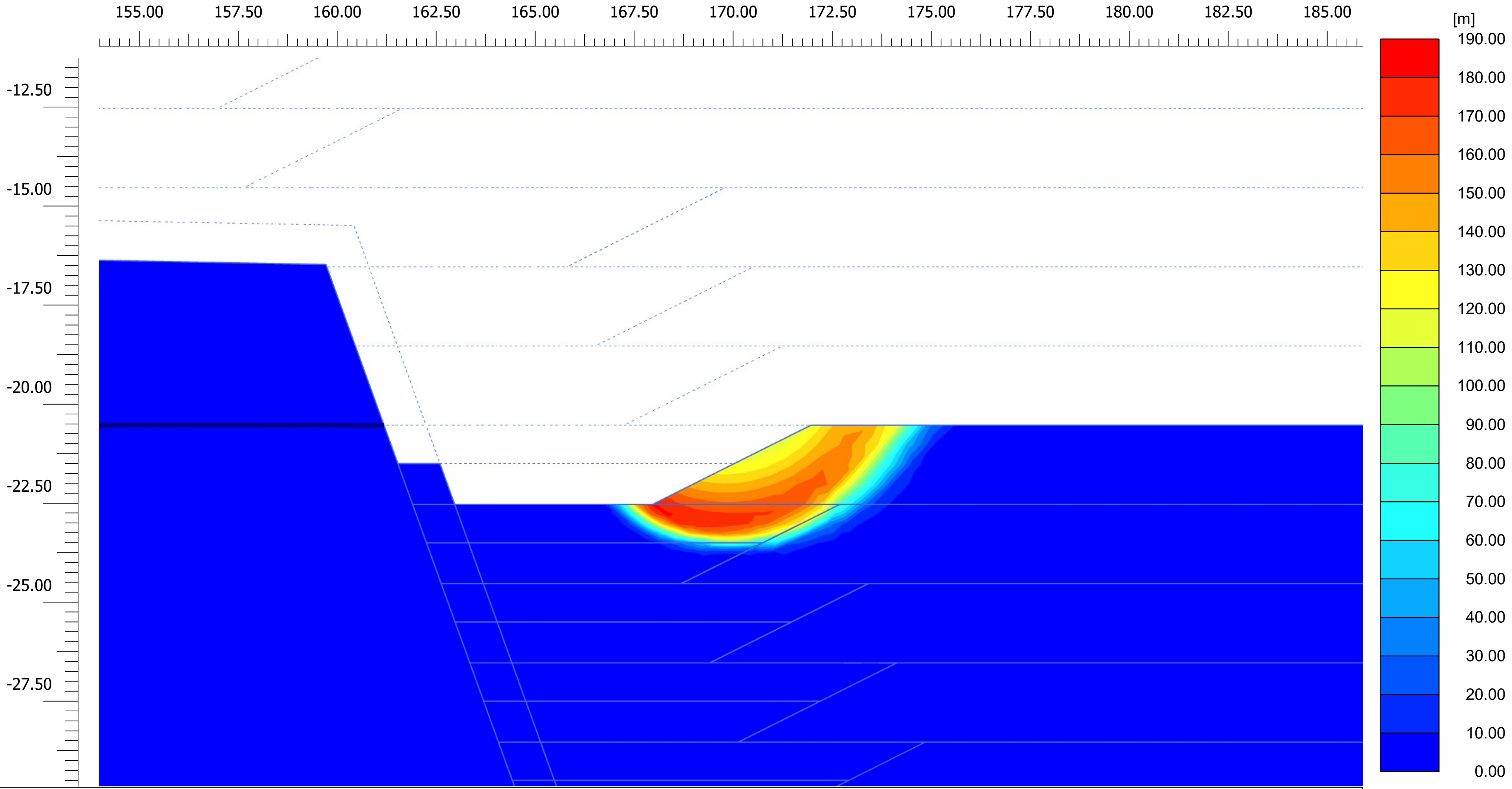
Incremental displacements |Δu| (scaled up 5.00 times)

Maximum value = 8.934 m (Element 2304 at Node 4935)

Project description Croft Quarry Infill			*Date* 13/03/2024
Project filename Croft Quarry Infill 2024 Mode ...	*Step* 783	*Company* Sirius Environmental Ltd	

Step info				
Phase	ECL30BS [Phase_61]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.2632E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.3616E-3	ΣM_{sf}	1.872
Time	Increment	0.000	End time	549.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8643
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	1029 kN/m^2			

Output Version 21.1.0.479



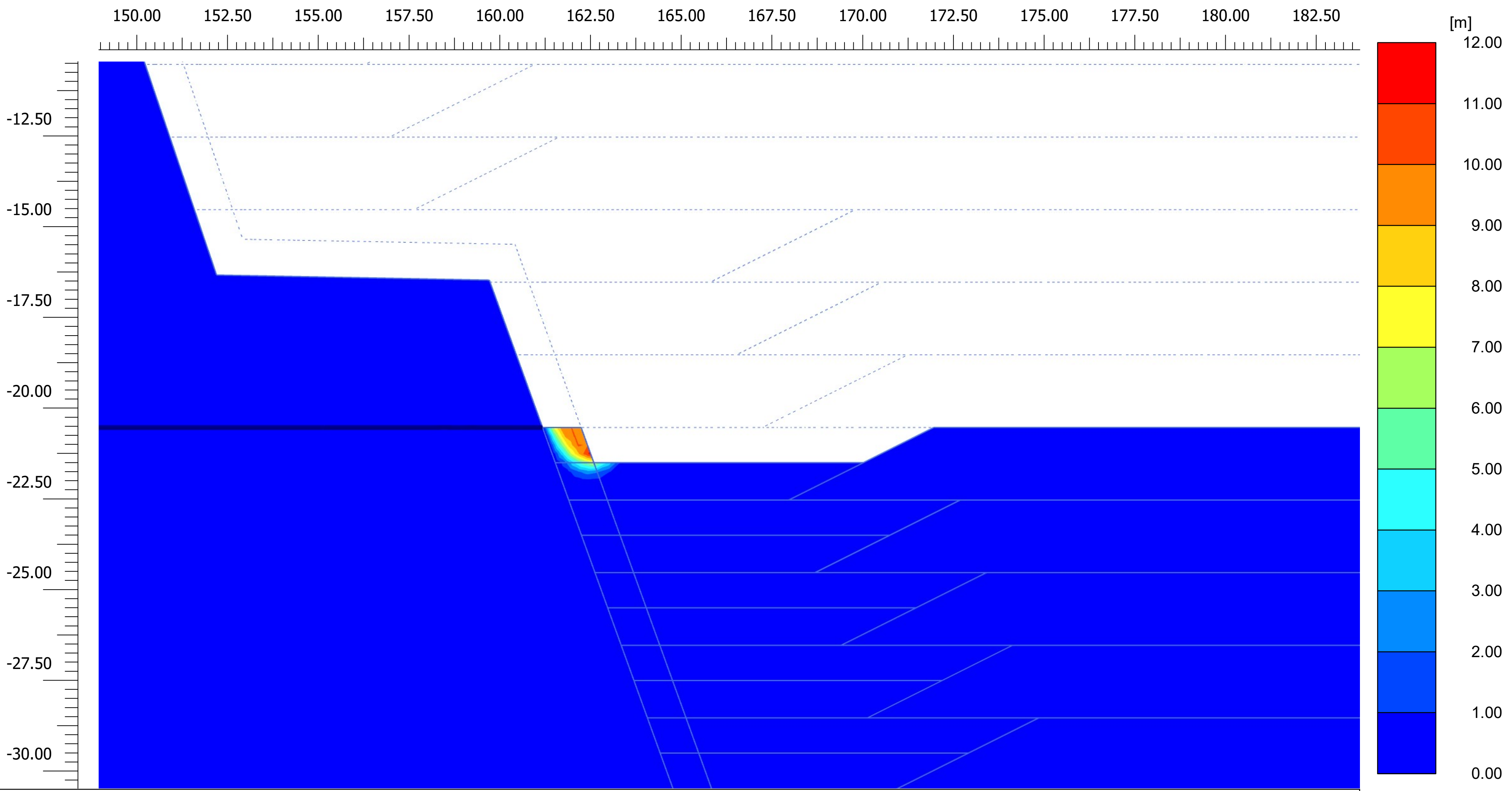
Incremental displacements |Δu| (scaled up 0.0500 times)

Maximum value = 182.3 m (Element 1818 at Node 6555)

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 333	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL35S [Phase_70]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	5.852E-12			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.2084E-3	ΣM_{sf}	1.412
Time	Increment	0.000	End time	1003
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8955
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	635.6 kN/m^2			

Output Version 21.1.0.479



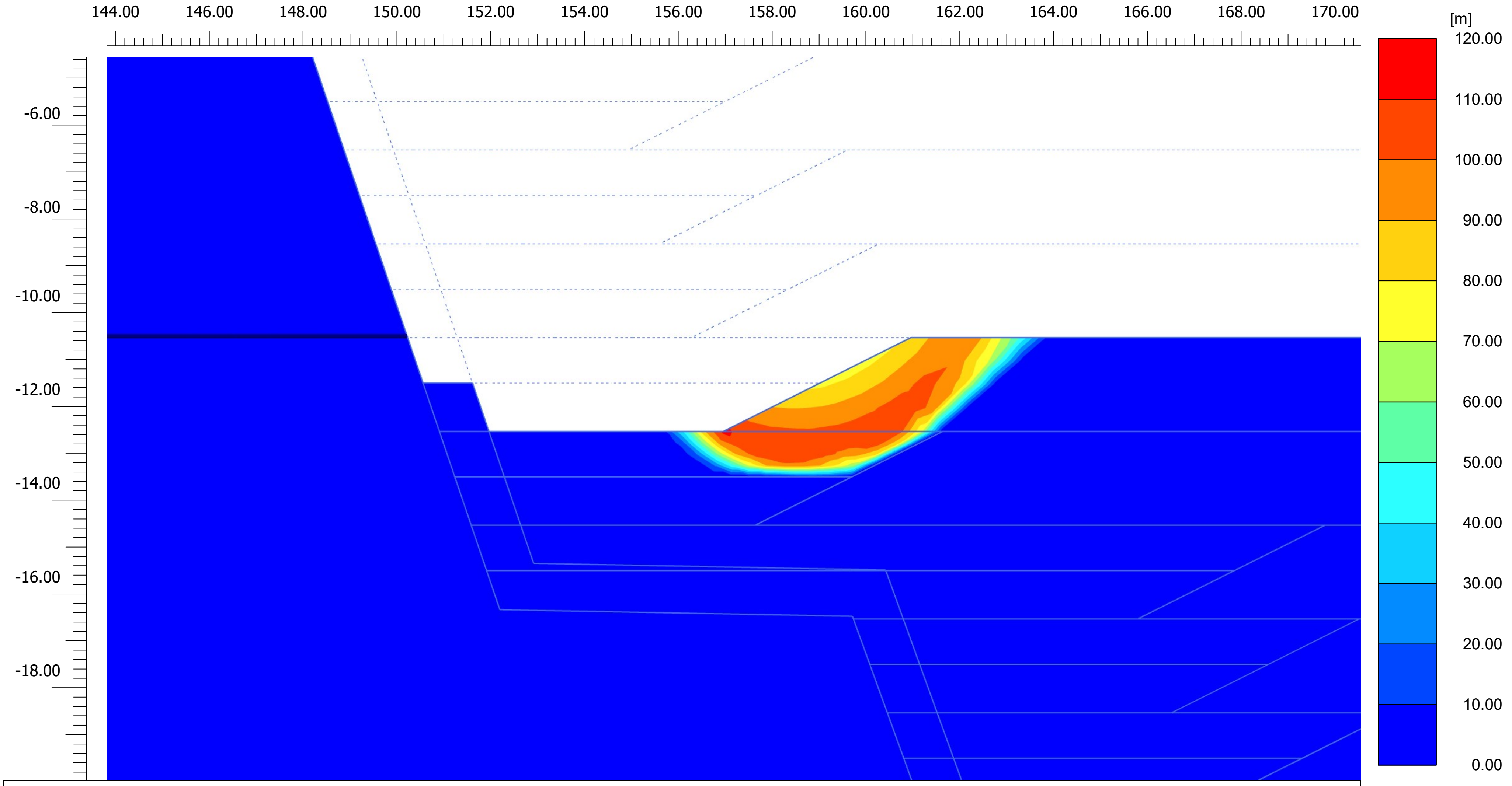
Incremental displacements |Δu| (scaled up 0.500 times)

Maximum value = 11.48 m (Element 1701 at Node 2201)

Project description			Date
Croft Quarry Infill			13/03/2024
Project filename	Step	Company	
Croft Quarry Infill 2024 Mode ...	283	Sirius Environmental Ltd	

Step info				
Phase	ECL35BS [Phase_71]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.2792E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	1.697E-3	ΣM_{sf}	1.954
Time	Increment	0.000	End time	1004
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.8957
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	1639 kN/m^2			

Output Version 21.1.0.479



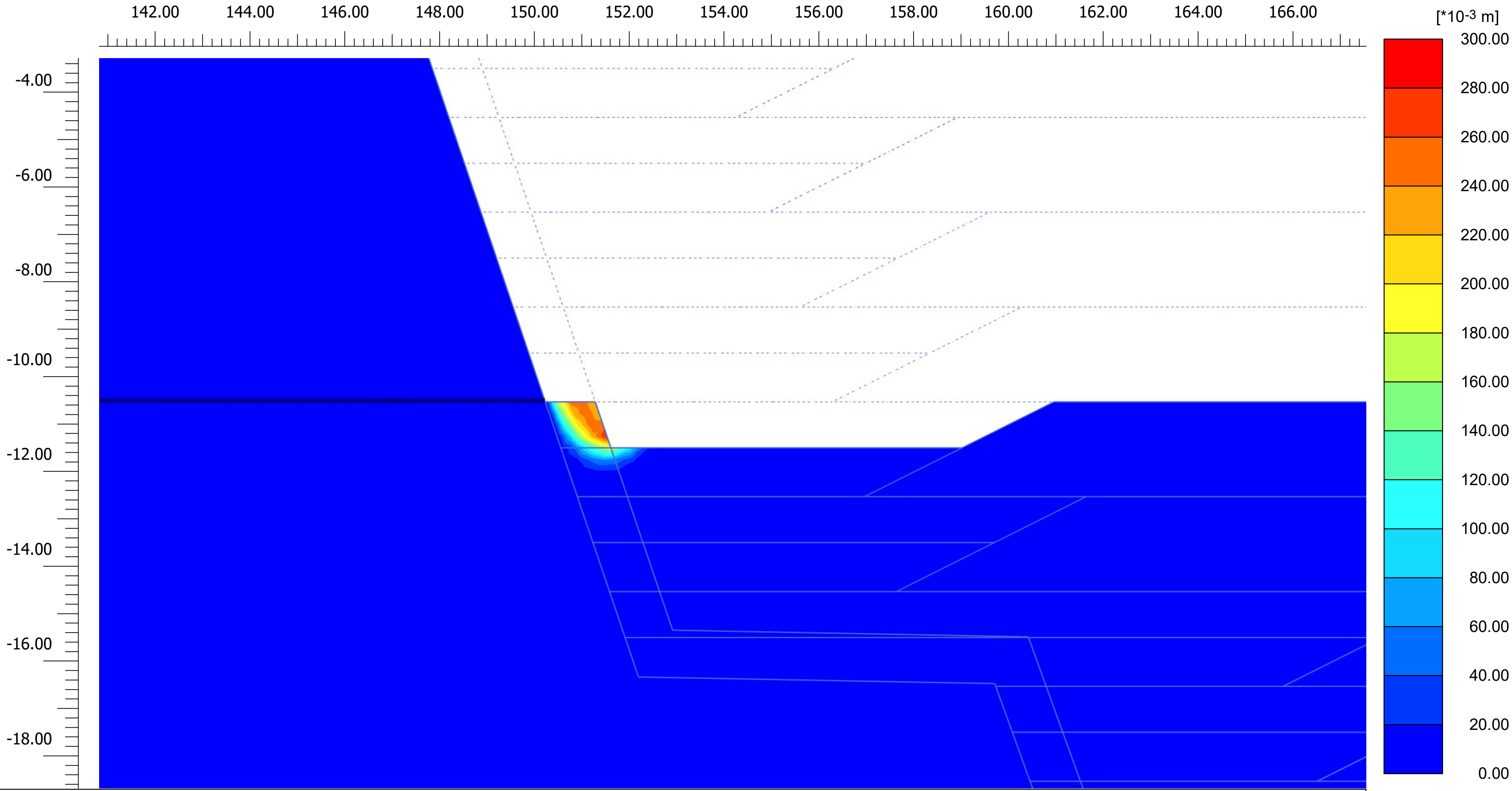
Incremental displacements |Δu| (scaled up 0.0500 times)

Maximum value = 113.4 m (Element 1415 at Node 2039)

Project description Croft Quarry Infill			*Date* 13/03/2024
Project filename Croft Quarry Infill 2024 Mode ...	*Step* 1324	*Company* Sirius Environmental Ltd	

Step info				
Phase	ECL40S [Phase_25]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-7.186E-12			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.1576E-3	ΣM_{sf}	1.565
Time	Increment	0.000	End time	487.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9285
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	668.6 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 50.0 times)

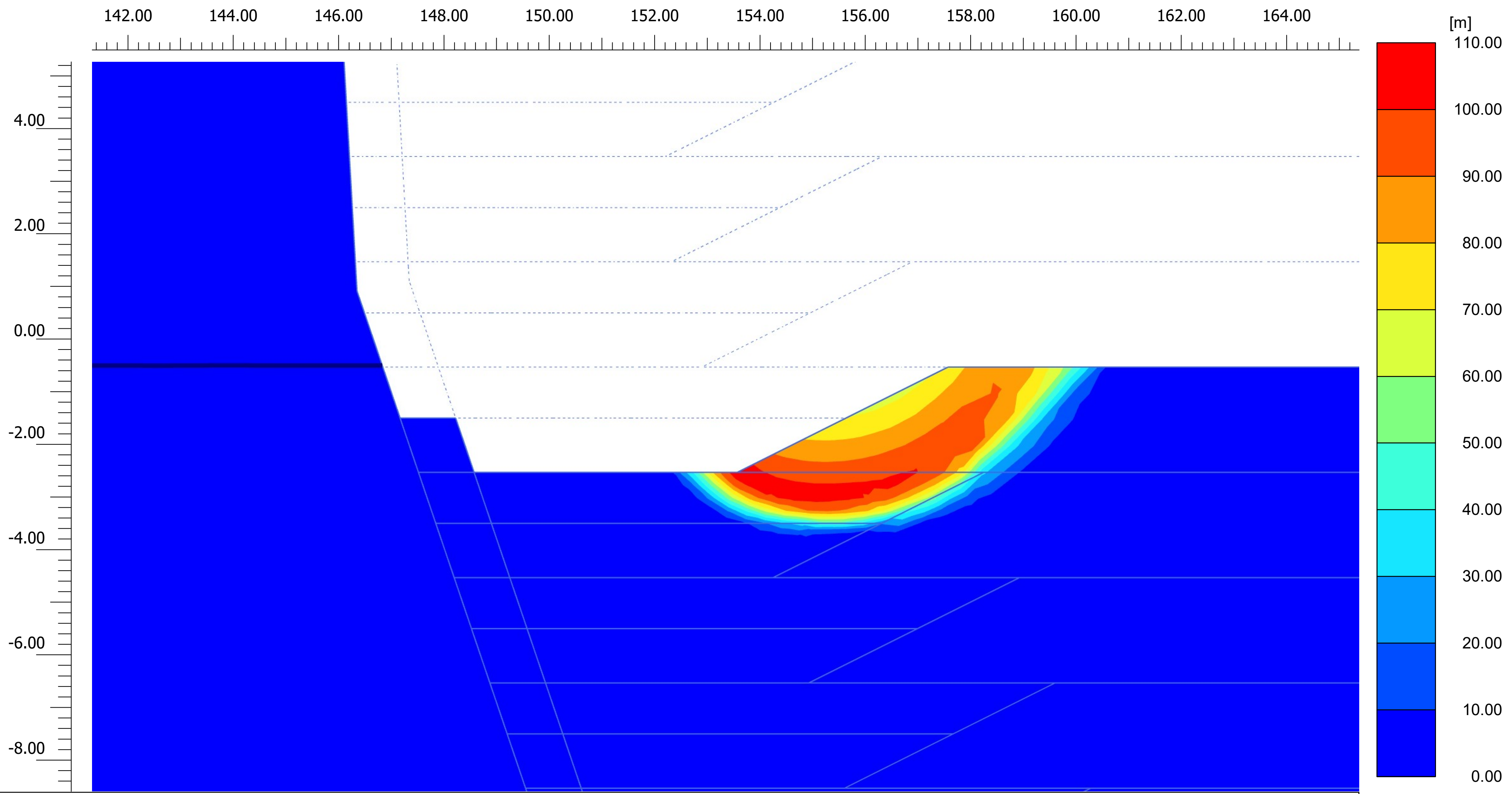
Maximum value = 0.2830 m (Element 1311 at Node 3469)

Project description	Date
Croft Quarry Infill	13/03/2024

Project filename	Step	Company
Croft Quarry Infill 2024 Mode ...	163	Sirius Environmental Ltd

Step info				
Phase	ECL40BS [Phase_26]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.03863E-6			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	1.113E-3	ΣM_{sf}	1.906
Time	Increment	0.000	End time	488.0
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9287
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	767.9 kN/m^2			

Output Version 21.1.0.479



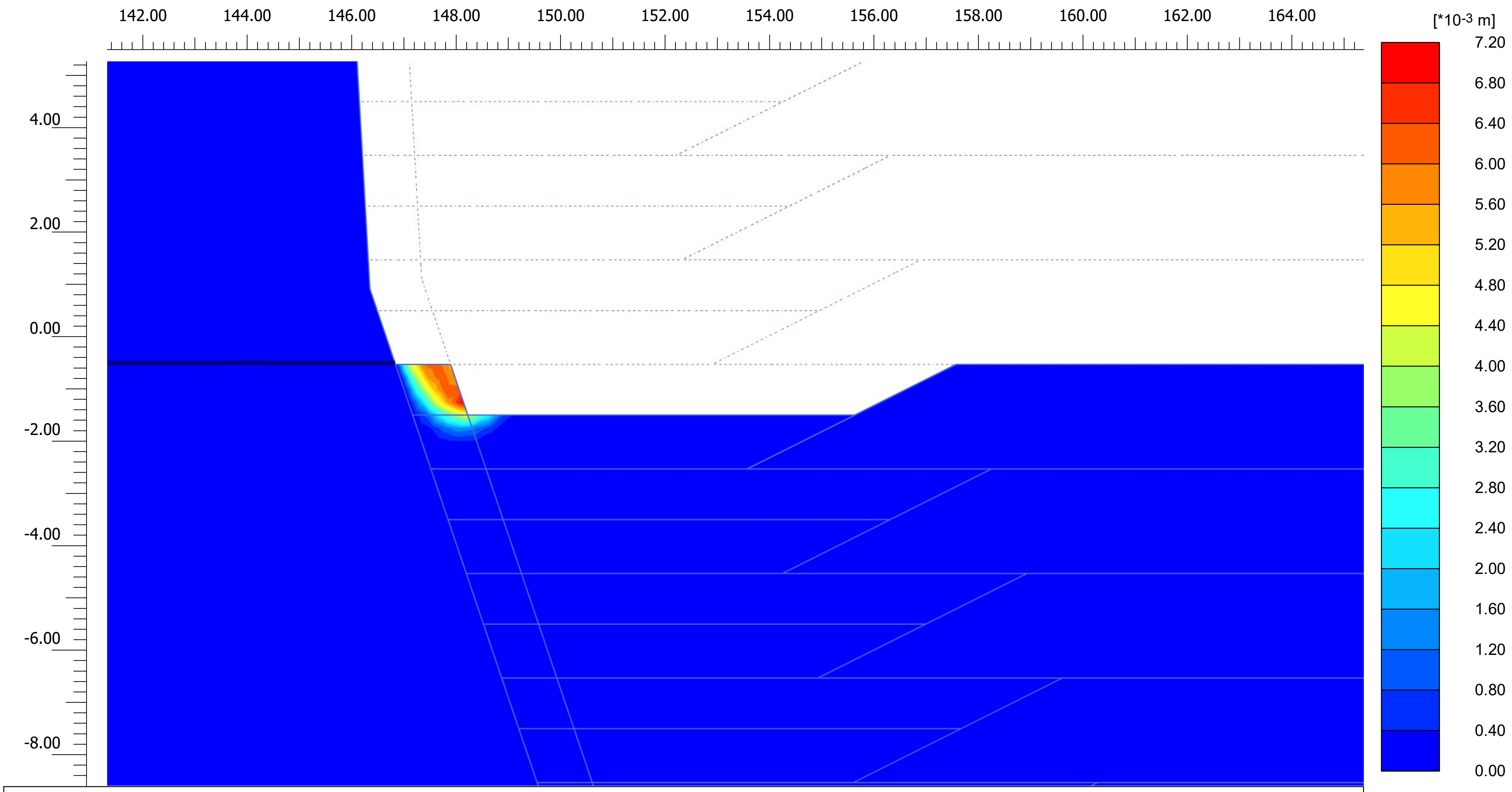
Incremental displacements |Δu| (scaled up 0.100 times)

Maximum value = 108.6 m (Element 775 at Node 304)

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 874	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL45S [Phase_66]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-0.03112E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.4885E-3	ΣM_{sf}	1.462
Time	Increment	0.000	End time	1096
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9629
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	1047 kN/m^2			

Output Version 21.1.0.479



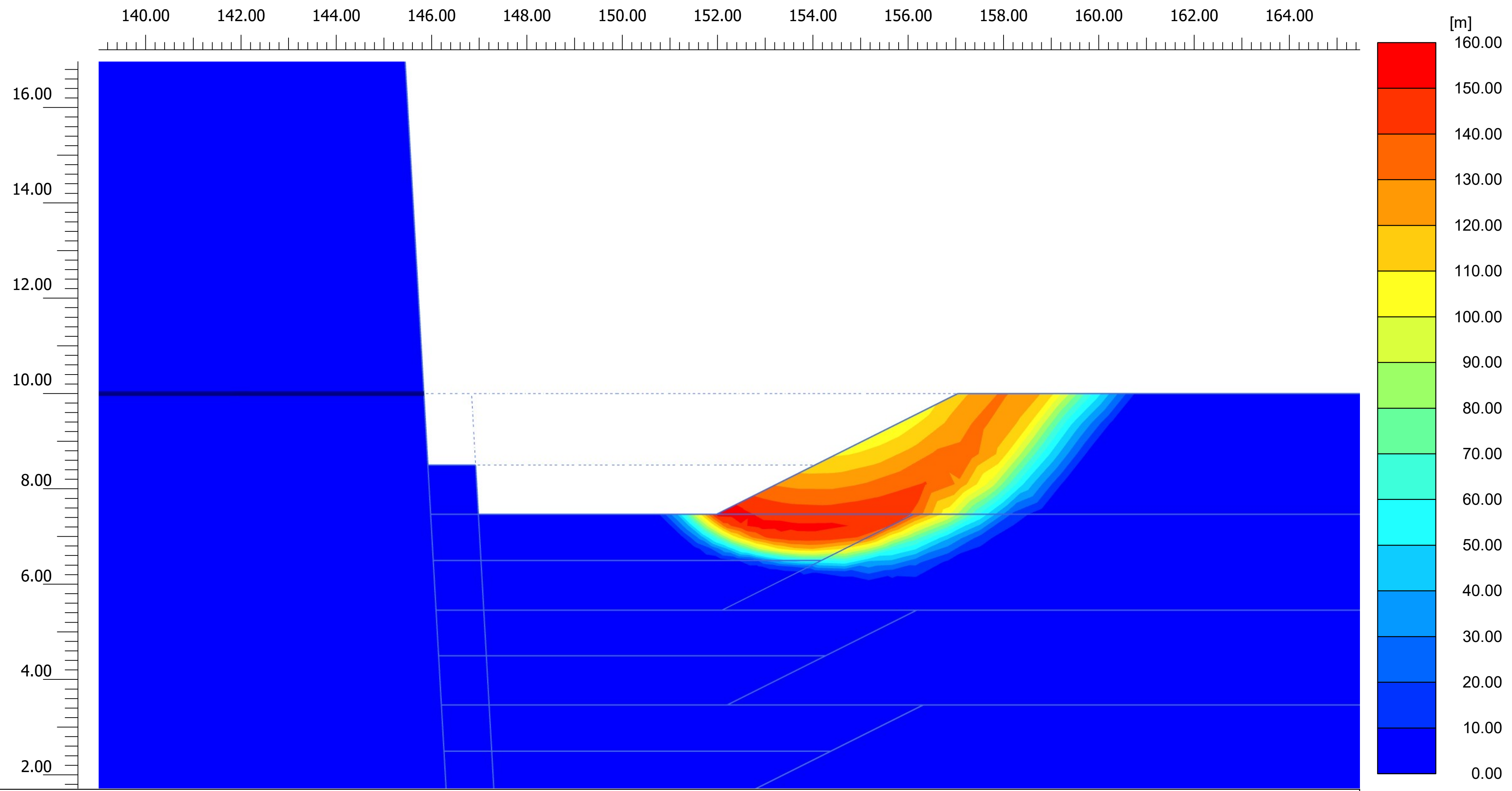
Incremental displacements |Δu| (scaled up 2.00*10³ times)

Maximum value = 7.077×10^{-3} m (Element 669 at Node 2417)

Sirius Environmental	*Project description* Croft Quarry Infill	*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL45BS [Phase_67]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.02756E-3			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.04870	ΣM_{sf}	2.017
Time	Increment	0.000	End time	1097
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9631
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	1150 kN/m^2			

Output Version 21.1.0.479



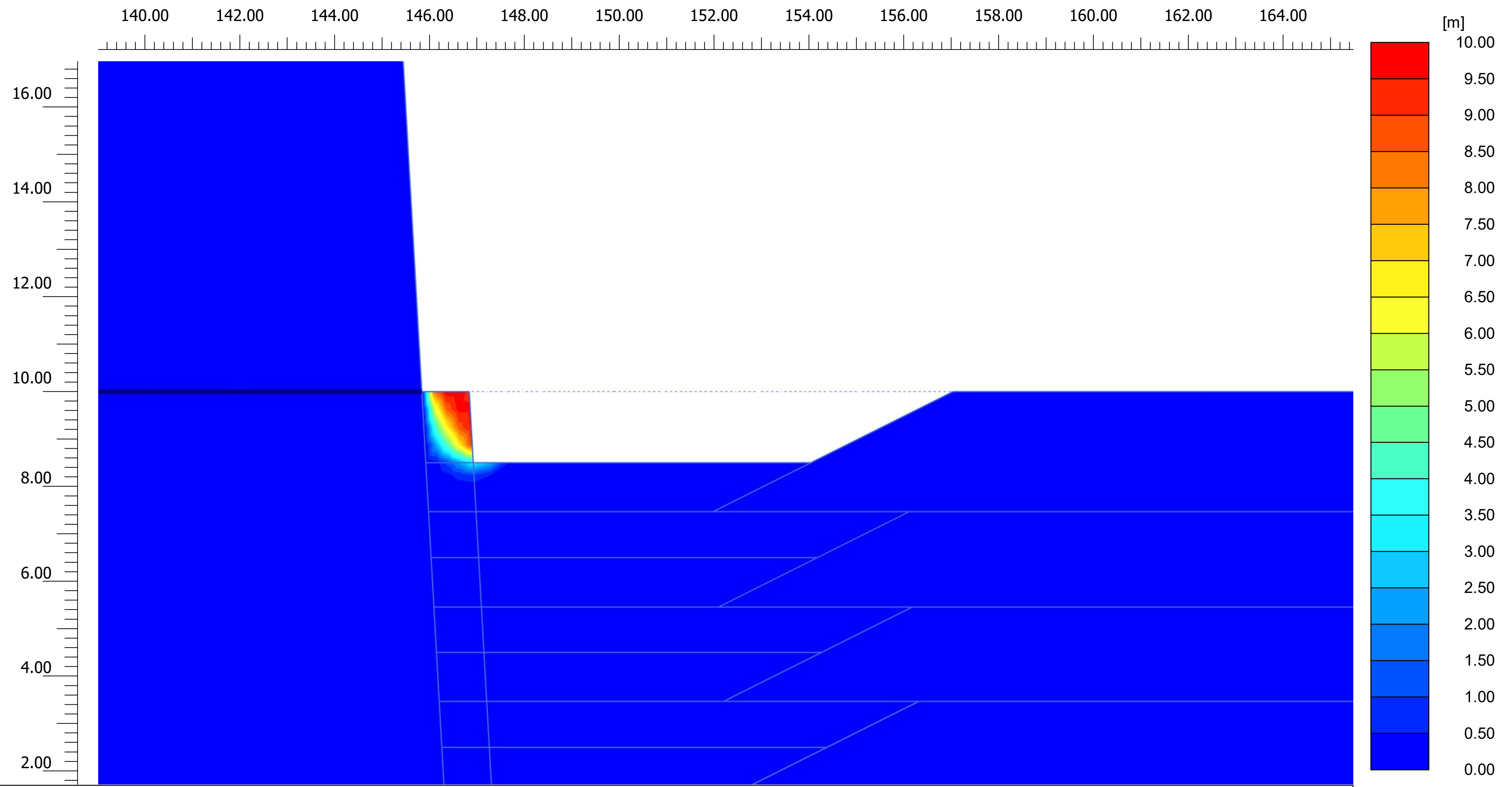
Incremental displacements |Δu| (scaled up 0.0500 times)

Maximum value = 154.5 m (Element 109 at Node 2102)

Project description		*Date*
Croft Quarry Infill		13/03/2024
Project filename Croft Quarry Infill 2024 Mode ...	*Step* 374	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL50S [Phase_76]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.05401E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.1095E-3	ΣM_{sf}	1.181
Time	Increment	0.000	End time	1704
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9996
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	1282 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 5.00 times)

Maximum value = 9.885 m (Element 12 at Node 1957)

Sirius Environmental	*Project description* Croft Quarry Infill		*Date* 13/03/2024
	Project filename Croft Quarry Infill 2024 Mode ...	*Step* 322	*Company* Sirius Environmental Ltd

Step info				
Phase	ECL50BS [Phase_77]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.01210E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.1155E-3	ΣM_{sf}	1.412
Time	Increment	0.000	End time	1705
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9997
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	1952 kN/m^2			

APPENDIX SRA3
Stability Risk Assessment: Temporary Waste Slope

(Doc. Ref.: AI1000/07.R1)

Sirius Environmental Ltd
4245 Park Approach
Thorpe Park
Leeds
LS15 8GB

0113 264 9960
www.thesiriusgroup.com

Aggregate Industries UK Limited
Bardon Hill
Coalville
Leicestershire
LE67 1TL

Date: 21/01/2022

Our Ref: AI1000/07.R1

Re: Croft Quarry Inert Infilling – Stability Risk Assessment

Introduction

Sirius Environmental Limited (Sirius) were commissioned by Aggregate Industries UK Limited (AI) to undertake a Stability Risk Assessment (SRA), at Croft Quarry to assess the temporary flank that shall be present during the infilling operations to ensure this remains stable. The temporary flank shall be confined with additional inert restoration material once the extraction of all the mineral reserve within the extension area of the site is completed.

This stability risk assessment shall only focus on the stability of the unconfined temporary flank which shall be present from a level of approximately -20mAOD to approximately 10mAOD. This SRA has not assessed the stability of the filling operation below a level of -20mAOD or the overall final profile for the site, as the material shall be confined on all sides in both scenarios, meaning there shall be no stability issues associated with these phases and therefore these have been screened out of this assessment.

Stability Risk Assessment Finite Element Model description

This stability risk assessment has assessed the worst section, to ensure the worst case scenario has been analysed. Within this SRA, varying slope profiles have been assessed for the temporary flank to ensure the resultant factors of safety are acceptable. The slopes assessed incorporate gradients of 1 in 3 (as per the original tipping profile provide by Aggregate Industries), 1 in 5 and 1 in 7.

The stability of the temporary flank at Croft Quarry has been assessed using the 2D finite element analysis software PLAXIS 2D (V21). This is a two-dimensional finite element programme intended for the analysis of deformation and stability in geotechnical engineering and is well suited for this stability risk assessment at Croft Quarry.

The underlying geology beneath the majority of the site comprises Quartz-diorite igneous bedrock. Within the proposed extension area, the British Geological Survey (BGS) maps indicate that additional bedrock, of the Mercia Mudstone Group overlaid by superficial marine sediments are present.

From monitoring data from the site it is apparent there is groundwater present within the Mercia Mudstone strata. However, there seems to be water present within the monitoring data from boreholes which penetrate into the underlying quartz diorite. In all associated documents it has determined that this is not considered groundwater, rather water that has been trapped within localised fissure and fracture networks. For this reason no groundwater is considered to be acting on the quartz-diorite and has not been included within the modelling.

The groundwater level from the Mercia Mudstone has not been considered as part of this stability risk assessment as the infilling operations are only to be infilled against the quartz-diorite quarry walls and hence will not have an impact of the stability of any temporary flanks.

Model Parameters

The material parameters used in the modelling are based on Sirius' previous stability models at Croft Quarry, as well as relevant literature to obtain parameters for the diorite bedrock and Sirius' recent experience with similar materials and projects for the restoration (infill) material. The most relevant material parameters used within the PLAXIS modelling are presented in Table SRA1A and Table SRA1B below. The full set of the model parameters used within the PLAXIS modelling are presented within Appendix SRA2.

Table SRA1A: Material Parameters for Restoration Infill Material

Material	Unit Weight (kN/m^3)	Effective Cohesion (kN/m^2)	Effective Angle of Friction (°)	Permeability (m/s)	Stiffness Moduli			Power (m)
					E_{50} (kPa)	E_{oed} (kPa)	E_{ur} (kPa)	
Restoration Soil	18-20	5	25	K=1E-8	4,000	4,000	12,000	1.0

Table SRA1B: Material Parameters for Quartz Diorite

Material	Unit Weight (kN/m^3)	E'_{rm} (kN/m^2)	V (nu)	Permeability (m/day)	Hoek-Brown Parameters			
					Uniaxial Compressive Strength (kN/m2)	Material Constant (mi)	Geological Strength Index	Disturbance Factor
Quartz-Diorite	23.0	1E6	0.250	K=3E-4	175E3	25	65	1

Stability Analysis

Safety analyses were run for each of the models considered under this assessment, allowing for the a factor of safety to be calculated for each lift associated with the construction of the temporary flank.

Phi C Reduction (factor of safety calculations) were only undertaken on the unconfined slope. The unconfined slope only occurs when the infilling is above approximately -20mAOD. Any infill material deposited below this level, shall be completed in layers from the bottom up and confined by the walls of the existing quarry. However, this has been included within the models to allow for the correct pore water pressures to be built up within the infill material.

1 in 3 Outer Slope Gradient

The results from the Phi C reduction runs with a temporary flank gradient of 1 in 3, based on an input rate of 750,000m^3 per annum, range from 1.715 to 0.9795. The lowest factor of safety is recorded when lift 5 is constructed, due to a greater effect from the build-up of positive excess pore water pressures.

The low factors of safety reported are due to the characteristics of the proposed restoration materials, which are assumed under a worst-case scenario to comprise only low permeability materials, with a permeability of K=1E-7m/s or lower. As this material is placed there is a build-up of positive excess pore water pressures within the material, which due to the permeability and lack of preferential pathways cannot easily dissipate. As a result of the generation of the excess positive pore water pressures there is no increase in the effective stress of the material and subsequently no increase in the shear strength of the material until the dissipation of these pore water pressures begins to occur, leading to slope instabilities and the low factors of safety reported in Table SRA2.

Mitigation whilst maintaining a 1 in 3 temporary flank slope gradient would be to allow sufficient time for the excess pore water pressures to dissipate, by slowing the rate of infilling. However this can take many years and is likely to result in unacceptable infilling rates based on the proposed input rate.

Table SRA2: Phi C Reduction Runs for 1 in 3 Temporary Flank

Phase Description	Description of Failure Surface	Factor of Safety (FoS)
Lift 1	Circular failure of outer edge of the temporary waste flank	1.715
Lift 2	Circular failure of outer edge of the temporary waste flank	1.288
Lift 3	Circular failure of outer edge of the temporary waste flank	1.138
Lift 4	Circular failure of outer edge of the temporary waste flank	1.083
Lift 5	Circular failure of outer edge of the temporary waste flank	0.9795
Lift 6	Circular failure of outer edge of the temporary waste flank	1.029

Table SRA2 above, presents the factors of safety reported from the Phi C reduction runs for the temporary flank with an outer slope gradient of 1 in 3. Unacceptable factors of safety were reported for a 1 in 3 gradient given the anticipated material and predicted input rate. Therefore in order to maintain the stability of the temporary flank, but ensure the proposed input rate of 750,000m^3 per annum can be achieved, alterations to the outer flank gradient is required. As part of this assessment, additional models were analysed with an outer slope gradients of 1 in 5 and 1 in 7, to see the effect this had on the stability. Tables SRA3 and SRA4 below show the results of the additional assessment.

1 in 5 Outer Slope Gradient

The results from the Phi C reduction with a temporary flank gradient of 1 in 5, range from 1.990 to 1.204.

Table SRA3: Phi C Reduction Runs for 1 in 5 Temporary Flank

Phase Description	Description of Failure Surface	Factor of Safety (FoS)
Lift 1	Circular failure of outer edge of the temporary waste flank	1.990
Lift 2	Circular failure of outer edge of the temporary waste flank	1.461
Lift 3	Circular failure of outer edge of the temporary waste flank	1.278
Lift 4	Circular failure of outer edge of the temporary waste flank	1.219
Lift 5	Circular failure of outer edge of the temporary waste flank	1.241
Lift 6	Circular failure of outer edge of the temporary waste flank	1.204

It can be seen that the factors of safety reported in Table SRA3 above for a 1 in 5 outer slope gradient, are greater than that reported for the 1 in 3 temporary slope gradient. The reported factors of safety for the 1 in 5 slope are above 1.2 for each of the lifts. Lifts 1 and 2 report a greater factor of safety due to these being the first few lifts when the slope is at a much lower height than when complete. These reported factors of safety of ~1.2 are lower than the usually acceptable 1.3, however this temporary slope will not be a permanent feature and shall be filled against once the extraction of the mineral has been completed in the extension area. Once infilling operations begin against this slope the unconfined slope height shall be reduced and the infill, shall begin to provide passive resistance to the unconfined slope causing an increase in the factor of safety from that reported in the tables above. As a result of this, the acceptable factors of safety for the temporary flank maybe reduced if the risk from any slope failure would likely be minimal and not have a detrimental impact on safety.

1 in 7 Outer Slope Gradient

The results from the Phi C reduction with a temporary waste flank gradient of 1 in 7 range from 2.346 to 1.315.

Table SRA4: Phi C Reduction Runs for 1 in 7 Temporary Flank

Phase Description	Description of Failure Surface	Factor of Safety (FoS)
Lift 1	Circular failure of outer edge of the temporary waste flank	2.346
Lift 2	Circular failure of outer edge of the temporary waste flank	1.710
Lift 3	Circular failure of outer edge of the temporary waste flank	1.317
Lift 4	Circular failure of outer edge of the temporary waste flank	1.338
Lift 5	Circular failure of outer edge of the temporary waste flank	1.315
Lift 6	Circular failure of outer edge of the temporary waste flank	1.682

It can be seen from the modelling undertaken as part of this assessment, that in order to achieve a factor of safety in excess of 1.3, for the proposed input rate of 750,000m^3 per annum, a minimum gradient of 1 in 7 should be constructed.

However, due to temporary nature of the flank a reduced factor of safety of 1.2, as stated in the previous section, can be deemed acceptable, therefore the outer slope could be constructed with a gradient of 1 in 5.

It is worth noting that the failure surfaces reported for each lift in all the three models are very similar in nature and comprise shallow circular failures on the outer edge of each lift of the placed restoration material. It should be noted that as the quarry restoration activities do not necessitate the construction of any engineered containment systems along the base and sidewalls of the quarry, any such slippages will not pose a significant risk to the environment.

Conclusion

This Stability Risk Assessment (SRA) has assessed the proposed temporary flank that shall be present during the infilling stage at Croft Quarry. This assessment has shown that in order to achieve a factor of safety of greater than 1.3 for each lift of restoration material, an outer flank gradient of 1 in 7 shall be required. However as this is a temporary flank that shall be filled against once mineral extraction within the extension area is completed, coupled with the fact that it is likely to only be a relatively short period of time where the slope is unconfined, a reduced factor of safety of 1.2 can be deemed acceptable. In order to achieve a factor of safety of 1.2, this assessment has found that the outer flank gradient required, shall not be greater than 1 in 5. This assessment has found that given the predicted low permeability nature of the infill material any slope with a steeper gradient than 1 in 5, combined with the predicted infill rate of 750,000m^3 per annum, it will result in unacceptable factors of safety, due to the build-up of positive excess pore water pressures within the material.

It should be noted that if the mineral reserve within the extension area is extracted more quickly than anticipated and before the infill material is placed above a level of approximately -20mAOD, material shall be able to be placed across the extension area in horizontal layers sooner. This shall lead to the material being confined on each side by the existing quarry walls. This would result in the unconfined temporary slope being reduced in height, meaning a steeper outer slope maybe acceptable.

As this stability risk assessment has been undertaken before any material has been imported to site, it is currently unknown what the characteristics of the imported material shall mainly comprise. Therefore, it is recommended that during the infilling stage up to the base of the temporary flank, regular visual inspections of the material are undertaken, as well as periodic geotechnical laboratory testing to determine site parameters. Prior to the construction of the temporary flank above -20mAOD, this stability risk assessment shall be reviewed and updated where necessary to take into account the characteristics of the imported material, utilising the information gathered from visual inspection and laboratory testing, the actual input rate compared with the predicted input rate assumed in this assessment and the extraction rates of the extension area, to reflect site conditions at the time of construction to ensure the modelling remains valid.

Yours sincerely

J. Davies

Jack Davies
Senior Engineer
For and on behalf of Sirius Environmental Limited

Appendix SRA1 – Drawings

Appendix SRA2 – Material Parameters

Appendix SRA3 – 1 in 3 Slope Gradient Plaxis Printouts

Appendix SRA4 – 1 in 5 Slope Gradient Plaxis Printouts

Appendix SRA5 – 1 in 7 Slope Gradient Plaxis Printouts

APPENDIX SRA1

DRAWINGS

- Application boundary
- Land ownership boundary
- Existing and proposed contours
- Existing footpath
- Existing bridleway
- Existing permissive footpath
- Existing woodland
- Existing water bodies
- Existing grassland
- Naturally regenerated scrub
- Local nature designation
- Conservation area
- Listed building
- Spot height (metres)
- Proposed footpath
- Proposed maintenance (surfaced)
- Proposed maintenance track (unsurfaced)
- New native woodland planting
- New native wet woodland planting
- New rock traps
- Areas of bare rock
- New water bodies
- New reed beds
- Bare rock areas for creation of acid grassland
- New marginal wet grassland/swamp
- New species rich grassland on restored quarry floor
- Section lines for restoration sections on drawing C14_LAN_039

INFORMATION

N

0 250 metres

CLIENT

AGGREGATE INDUSTRIES

ESP
- Chartered Surveyors
- Chartered Landscape Architects
- Environmental Consultants
- Health and Safety Consultants

ESP
The Creative Industries Centre
Glaisher Drive
Wolverhampton
WV10 9TG
Tel: 01902 771331

PROJECT

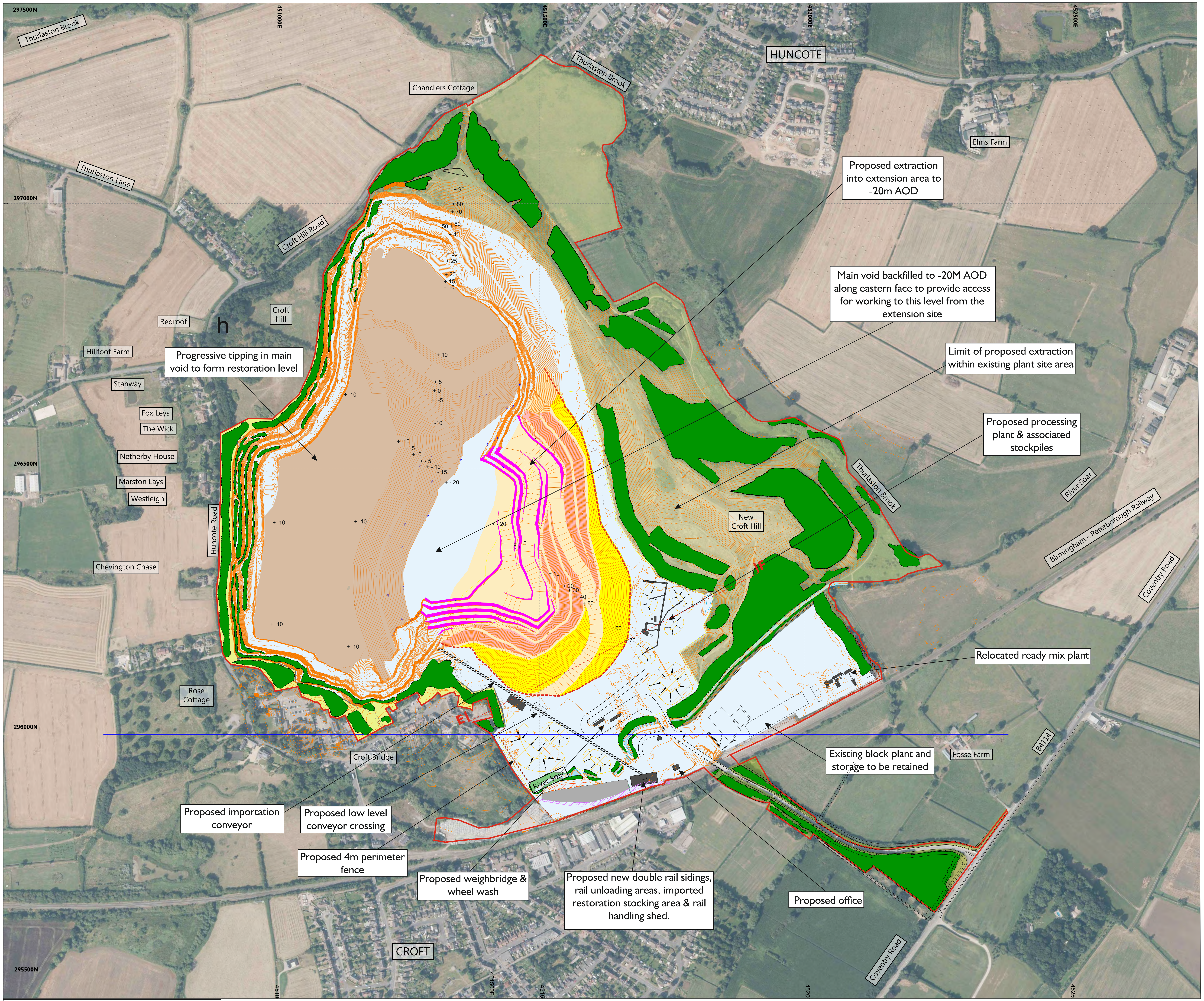
Croft Quarry

TITLE

Restoration Plan

SCALE	DRAWN BY	DATE
1:5000@A2	MRH/RD	April 2019

DRAWING NUMBER	REV
C14_LAN_035	D Feb 20



Development stage; Backfill stage 1

LEGEND

- Application boundary
- Limit of excavation of proposed extension
- Restored/naturally regenerated areas within application boundary
- Contours
- Existing woodland & scrub
- Extent of currently consented mineral extraction and other operations
- Extent of proposed lateral extension
- Superficial overburden faces
- Mercia Mudstone overburden faces
- Diorite mineral faces
- Quarry void infill material
- F Section line for operational section on drawing C14_LAN_040

INFORMATION

0 500 metres

CLIENT

AGGREGATE INDUSTRIES

ESP
Chartered Surveyors
Chartered Landscape Architects
Environmental Consultants
Health and Safety Consultants
ESP Ltd
The Creative Industries Centre
Glaisher Drive
Wolverhampton
WV10 9TG
Tel: 01902 771311

PROJECT

Croft Quarry

TITLE

Development Stages; Plan 3

SCALE	DRAWN BY	DATE
1:5000 @A2	RD/AC	March 2019

DRAWING NUMBER	REV
C14_LAN_038	C May 20

APPENDIX SRA2

MATERIAL PARAMETERS

Material set		
Identification number		1
Identification		Diorite
Material model		Hoek-Brown
Drainage type		Drained
Colour		RGB 153, 147, 143
Comments		
General properties		
γ_{unsat}	kN/m³	23.00
γ_{sat}	kN/m³	23.00
Advanced		
Void ratio		
Dilatancy cut-off		No
e_{init}		0.5000
e_{min}		0.000
e_{max}		999.0
Stiffness		
E'_{rm}	kN/m²	1.000E6
ν (nu)		0.2500
Hoek-Brown parameters		
$\lvert\sigma_{ci}\rvert$	kN/m²	175.0E3
m_i		25.00
GSI		65.00
D		1.000
Hoek-Brown criterion		
m_b		2.052
s		2.928E-3
a		0.5020
Rock mass parameters		
σ_t	kN/m²	249.7
σ_c	kN/m²	-9361
Dilatancy angle		
ψ_{max}	°	0.000
σ_{ψ}	kN/m²	0.000

Identification		Diorite
Advanced		
Undrained behaviour		
Undrained behaviour		Standard
Stiffness		
Stiffness		Standard
Strength		
Strength		Rigid
R_{inter}		1.000
Consider gap closure		Yes
Real interface thickness		
δ_{inter}		0.000
Groundwater		
Cross permeability		Impermeable
Drainage conductivity, dk	m^3/day/m	0.000
Thermal		
R	m^2 K/kW	0.000
K0 settings		
K_0 determination		Automatic
$K_{0,x} = K_{0,z}$		Yes
$K_{0,x}$		0.5000
$K_{0,z}$		0.5000
Model		
Data set		Standard
Soil		
Type		Coarse
< 2 μm	%	10.00
2 μm - 50 μm	%	13.00
50 μm - 2 mm	%	77.00

Identification		Diorite
Flow parameters		
Use defaults		None
k_x	m/day	0.3000E-3
k_y	m/day	0.3000E-3
$-\psi_{unsat}$	m	10.00E3
e_{init}		0.5000
Change of permeability		
c_k		1000E12
Parameters		
c_s	kJ/t/K	0.000
λ_s	kW/m/K	0.000
ρ_s	t/m³	0.000
Solid thermal expansion		Volumetric
α_s	1/K	0.000
D_v	m²/day	0.000
f_{Tv}		0.000
Unfrozen water content		None

Material set		
Identification number		2
Identification		Restoration Soil
Material model		Hardening soil
Drainage type		Undrained (A)
Colour		RGB 142, 70, 11
Comments		
General properties		
γ_{unsat}	kN/m³	18.00
γ_{sat}	kN/m³	20.00
Advanced		
Void ratio		
Dilatancy cut-off		No
e_{init}		0.5000
e_{min}		0.000
e_{max}		999.0
Stiffness		
E_{50}^{ref}	kN/m²	4000
E_{oed}^{ref}	kN/m²	4000
E_{ur}^{ref}	kN/m²	12.00E3
power (m)		1.000
Alternatives		
Use alternatives		No
C_c		0.08625
C_s		0.02587
e_{init}		0.5000
Strength		
c_{ref}	kN/m²	5.000
φ (phi)	°	25.00
ψ (psi)	°	0.000

Identification		Restoration Soil
Advanced		
Set to default values		Yes
Stiffness		
ν_{ur}		0.2000
p_{ref}	kN/m²	100.0
K_0^{nc}		0.5774
Strength		
c_{inc}	kN/m²/m	0.000
y_{ref}	m	0.000
R_f		0.9000
Tension cut-off		Yes
Tensile strength	kN/m²	0.000
Undrained behaviour		
Undrained behaviour		Standard
Skempton-B		0.9866
ν_u		0.4950
$K_{w,ref}$ / n	kN/m²	491.7E3
Stiffness		
Stiffness		Standard
Strength		
Strength		Rigid
R_{inter}		1.000
Consider gap closure		Yes
Real interface thickness		
δ_{inter}		0.000
Groundwater		
Cross permeability		Impermeable
Drainage conductivity, dk	m³/day/m	0.000
Thermal		
R	m² K/kW	0.000

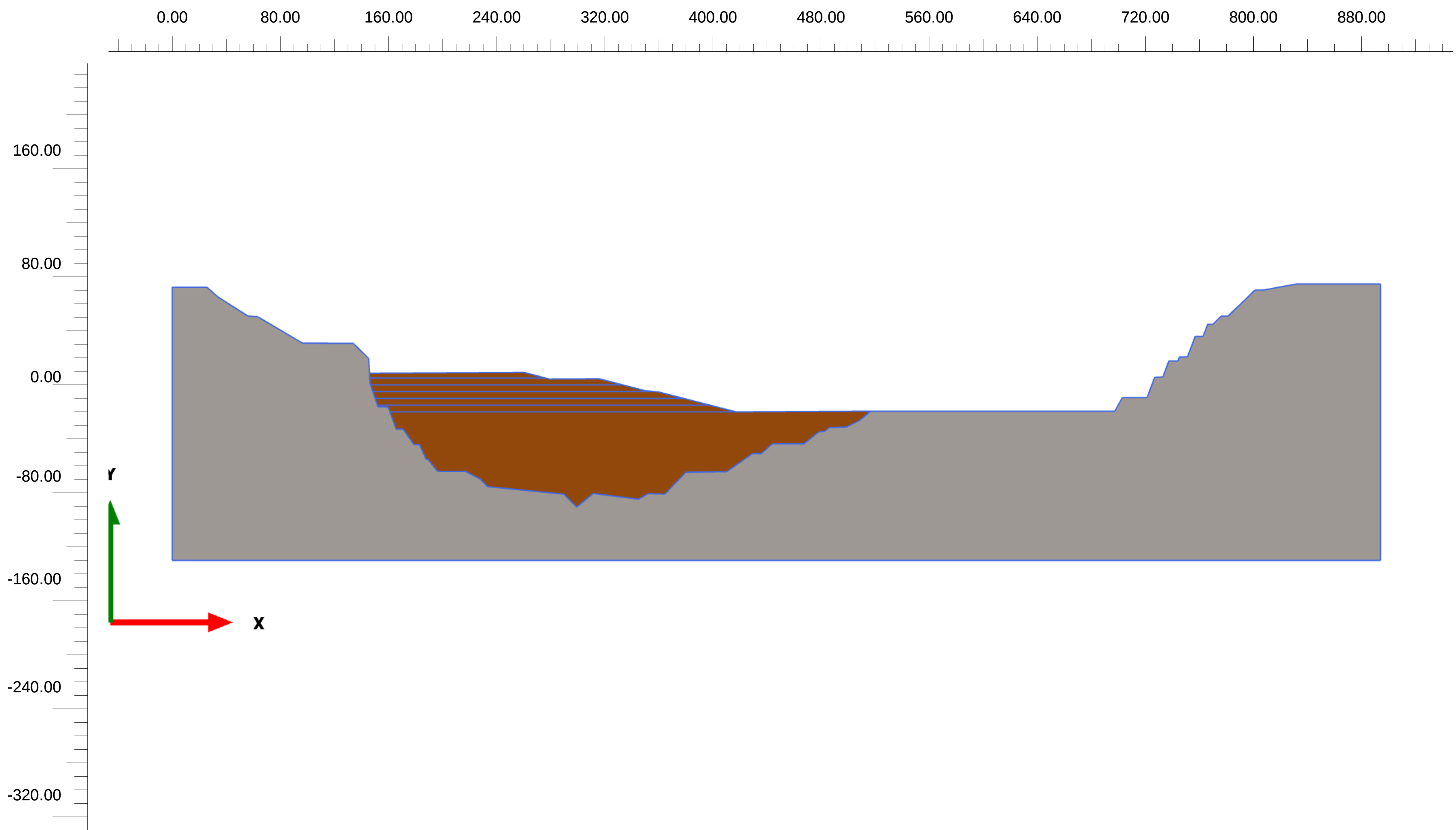
Identification		Restoration Soil
K0 settings		
K_0 determination		Automatic
$K_{0,x} = K_{0,z}$		Yes
$K_{0,x}$		0.5774
$K_{0,z}$		0.5774
Overconsolidation		
OCR		1.000
POP	kN/m²	0.000
Model		
Data set		Standard
Soil		
Type		Coarse
< 2 µm	%	10.00
2 µm - 50 µm	%	13.00
50 µm - 2 mm	%	77.00
Flow parameters		
Use defaults		None
k_x	m/day	0.8640E-3
k_y	m/day	0.8640E-3
$-\psi_{unsat}$	m	10.00E3
e_{init}		0.5000
S_s	1/m	0.000
Change of permeability		
c_k		1000E12

Identification		Restoration Soil
Parameters		
c_s	kJ/t/K	0.000
λ_s	kW/m/K	0.000
ρ_s	t/m³	0.000
Solid thermal expansion		Volumetric
α_s	1/K	0.000
D_v	m²/day	0.000
f_{Tv}		0.000
Unfrozen water content		None

APPENDIX SRA3

1 IN 3 SLOPE GRADIENT PLAXIS PRINTOUTS

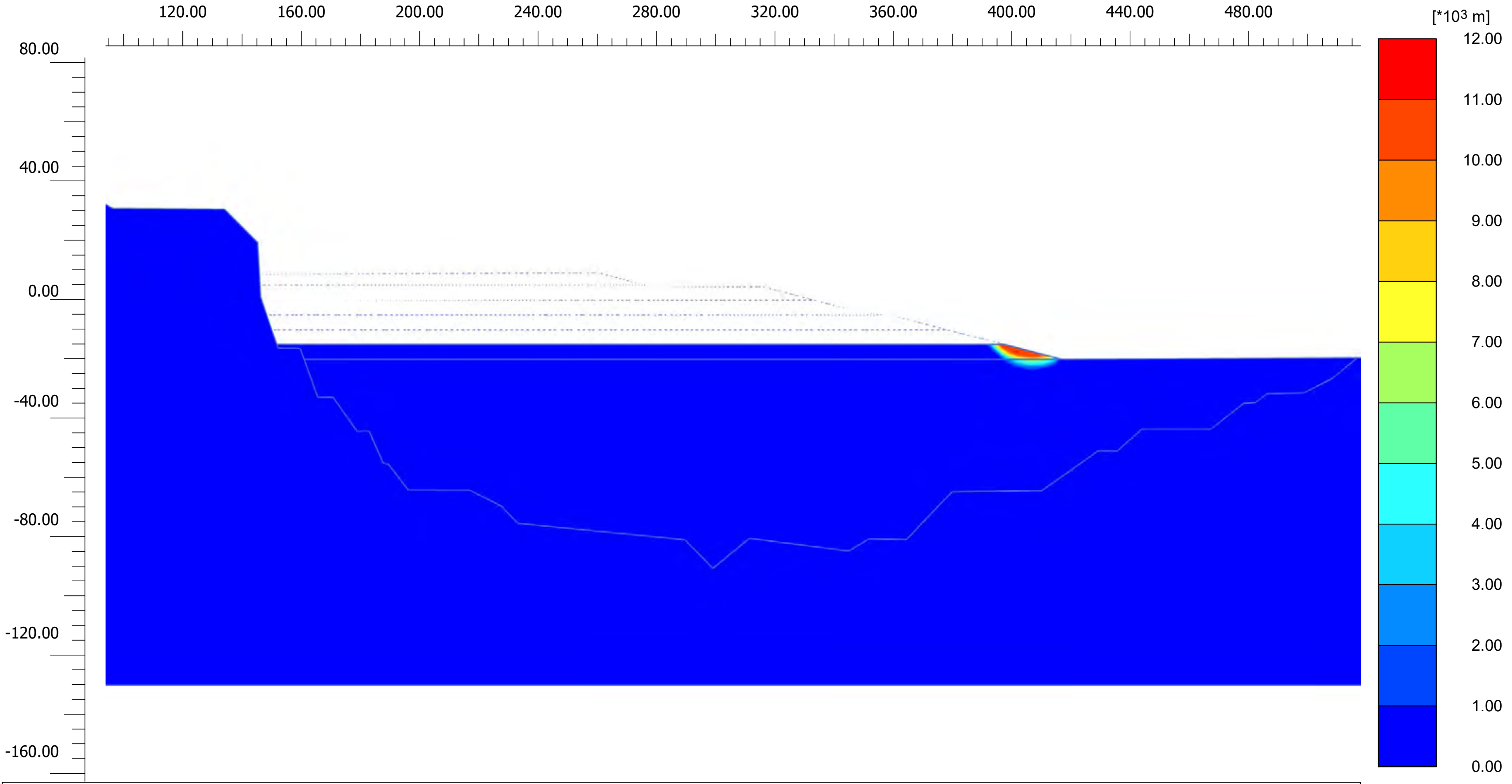
Output Version 21.1.0.479



Connectivity plot

Project description Croft Quarry - Restoration Infill 1 in 3 Geometry			*Date* 13/01/2022
Project filename Croft Quarry - Restoration ...	*Step* 31	*Company* Sirius Environmental Ltd	

Output Version 21.1.0.479



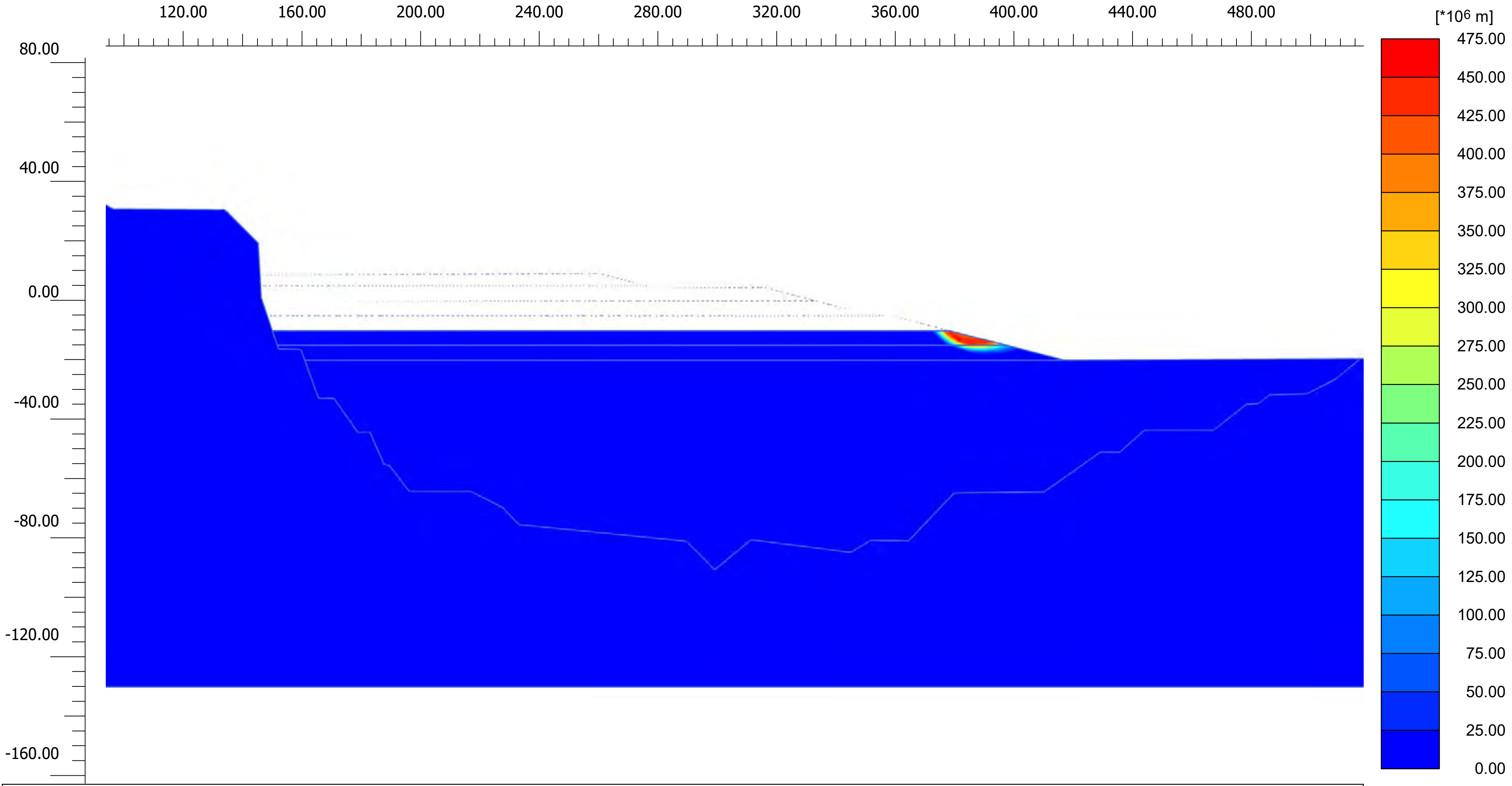
Incremental displacements |Δu| (scaled up $2.00*10^{-3}$ times)

Maximum value = $11.13*10^{3}$ m (Element 393 at Node 5990)

Project description	Croft Quarry - Restoration Infill to -15mAOD		*Date* 13/01/2022
Project filename Croft Quarry - Restoration Infill	*Step* 657	*Company* Sirius Environmental Ltd	

Step info				
Phase	L1S [Phase_13]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	2.459E-12			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.1275E-3	ΣM_{sf}	1.715
Time	Increment	0.000	End time	6753
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9639
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	436.8 kN/m^2			

Output Version 21.1.0.479



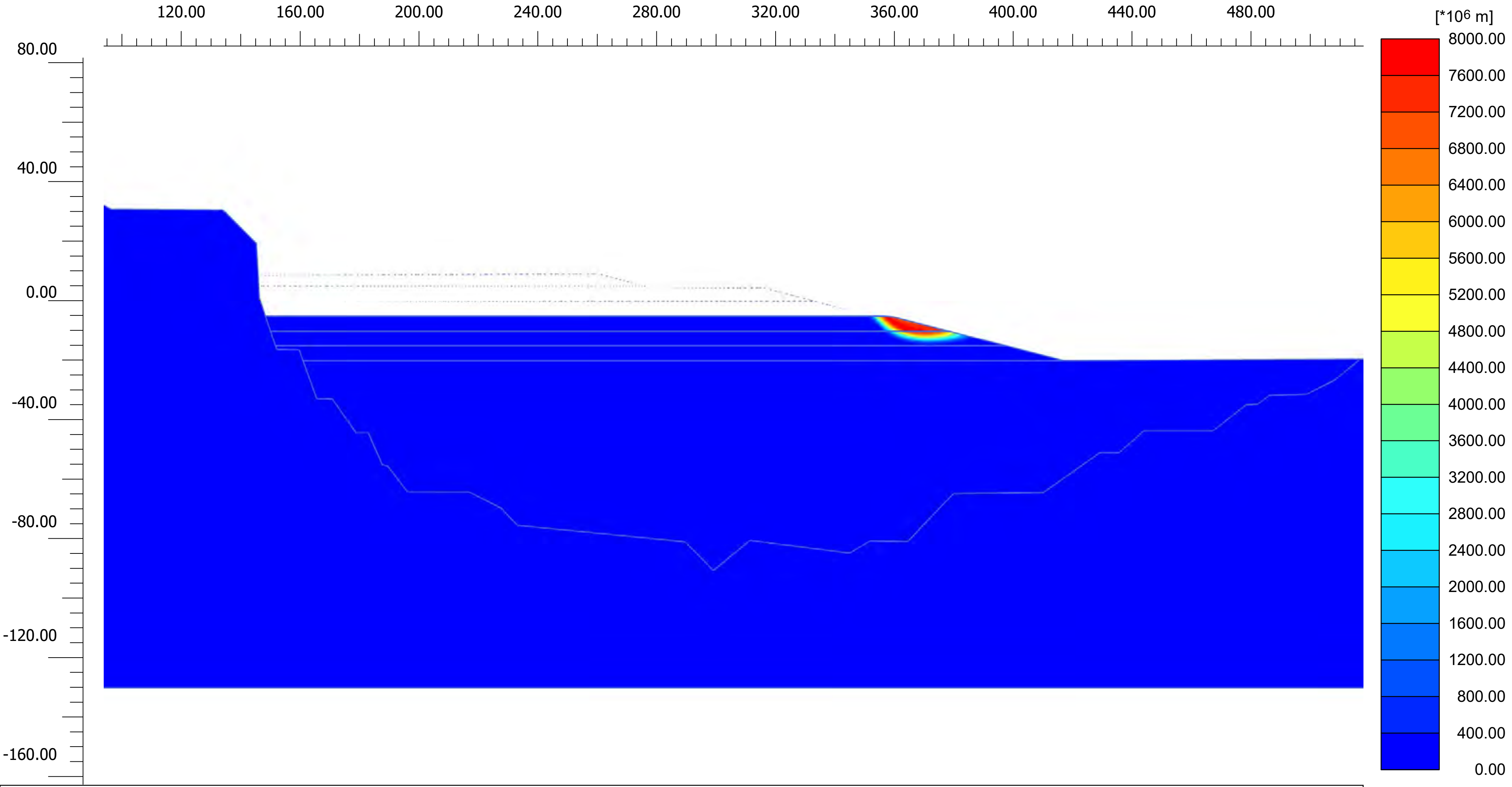
Incremental displacements |Δu| (scaled up $0.0500*10^{-6}$ times)

Maximum value = $463.0*10^{6}$ m (Element 315 at Node 5636)

Project description Croft Quarry - Restoration Infill to -10mAOD			*Date* 13/01/2022
Project filename Croft Quarry - Restoration Infill	*Step* 557	*Company* Sirius Environmental Ltd	

Step info				
Phase	L2S [Phase_12]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	1.000			
Relative stiffness	-0.08037E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.4483E-3	ΣM_{sf}	1.288
Time	Increment	0.000	End time	7118
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9732
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	290.4 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up $5.00*10^{-9}$ times)

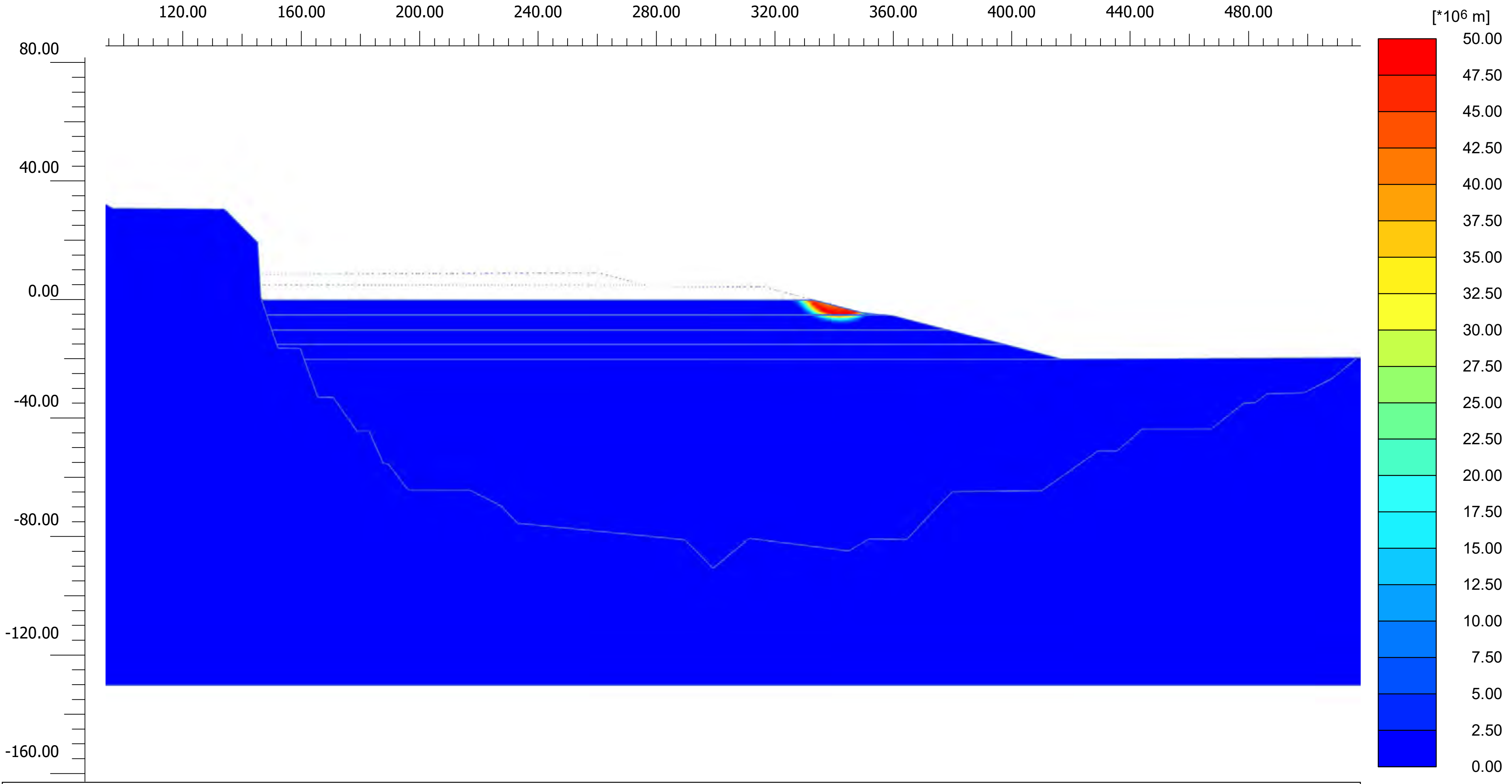
Maximum value = $7.946*10^{9}$ m (Element 213 at Node 5185)

Project description	Date
Croft Quarry - Restoration Infill to -5mAOD	13/01/2022

Project filename	Step	Company
Croft Quarry - Restoration Infill	457	Sirius Environmental Ltd

Step info				
Phase	L3S [Phase_11]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.08701E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.6608E-3	ΣM_{sf}	1.138
Time	Increment	0.000	End time	7483
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9818
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	300.2 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 0.500*10^{-6} times)

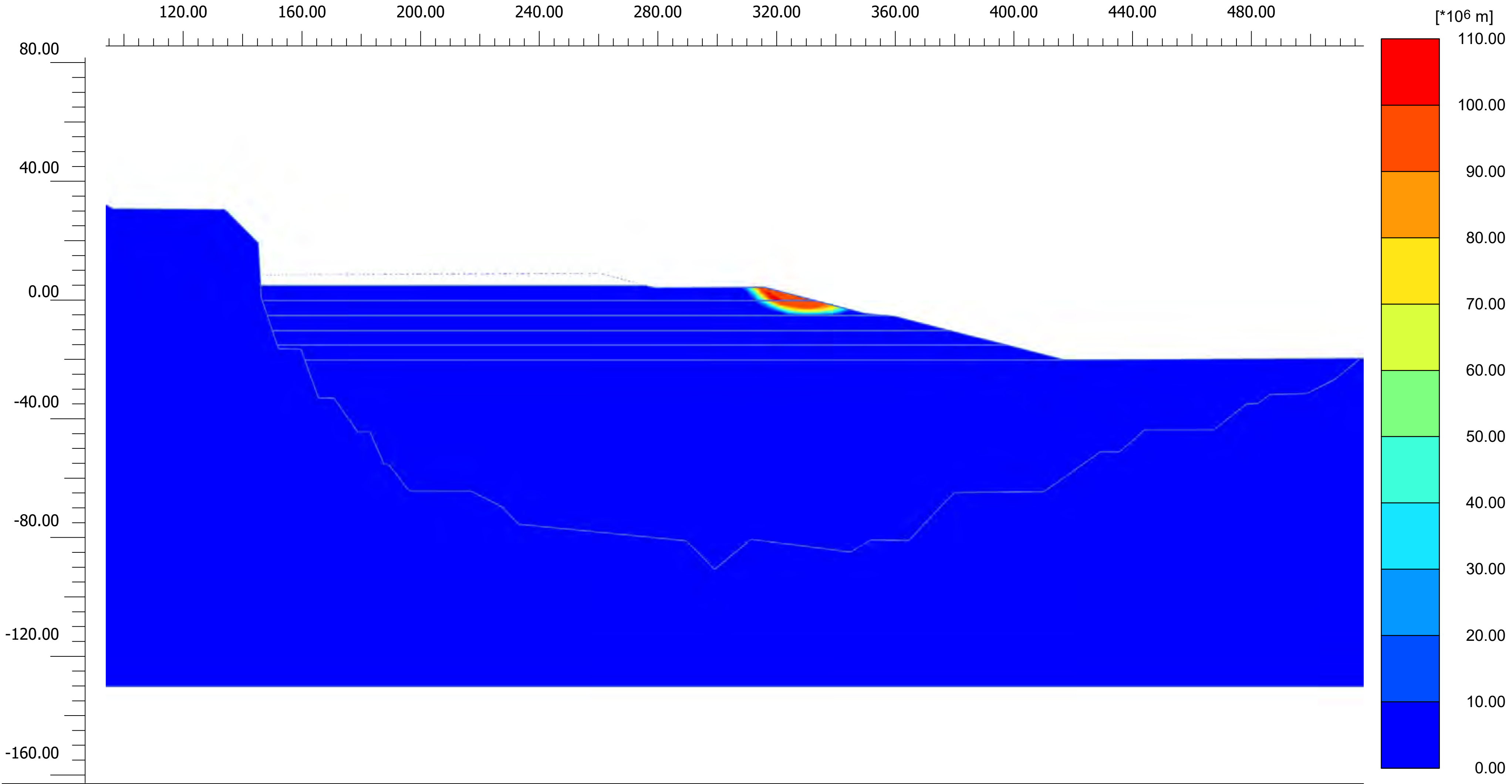
Maximum value = 49.83*10^{6} m (Element 196 at Node 3969)

Project description		Date
Croft Quarry - Restoration Infill to 0mAOD		13/01/2022

Project filename	Step	Company
Croft Quarry - Restoration Infill	357	Sirius Environmental Ltd

Step info				
Phase	L4S [Phase_10]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-0.6686E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.3070E-3	ΣM_{sf}	1.083
Time	Increment	0.000	End time	7848
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9895
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	308.5 kN/m^2			

Output Version 21.1.0.479



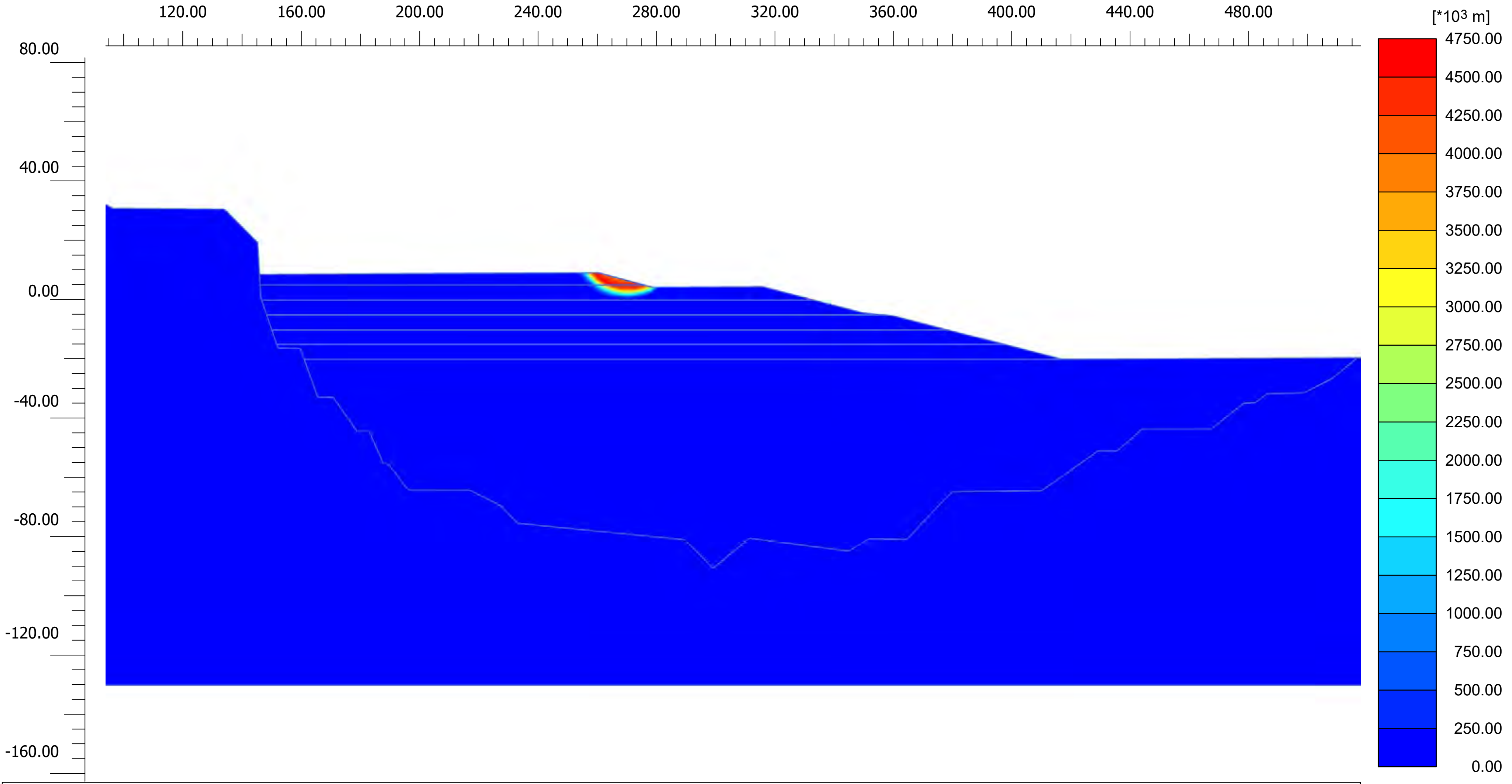
Incremental displacements |Δu| (scaled up 0.200*10^{-6} times)

Maximum value = 103.7*10^{6} m (Element 52 at Node 3559)

Sirius Environmental	*Project description* Croft Quarry - Restoration Infill to 5mAOD		*Date* 13/01/2022
	Project filename Croft Quarry - Restoration Infill	*Step* 257	*Company* Sirius Environmental Ltd

Step info				
Phase	L5S [Phase_9]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	-0.1717E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.03186E-3	ΣM_{sf}	0.9795
Time	Increment	0.000	End time	8213
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9962
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	377.9 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up $5.00*10^{-6}$ times)

Maximum value = $4.618*10^{6}$ m (Element 47 at Node 5790)

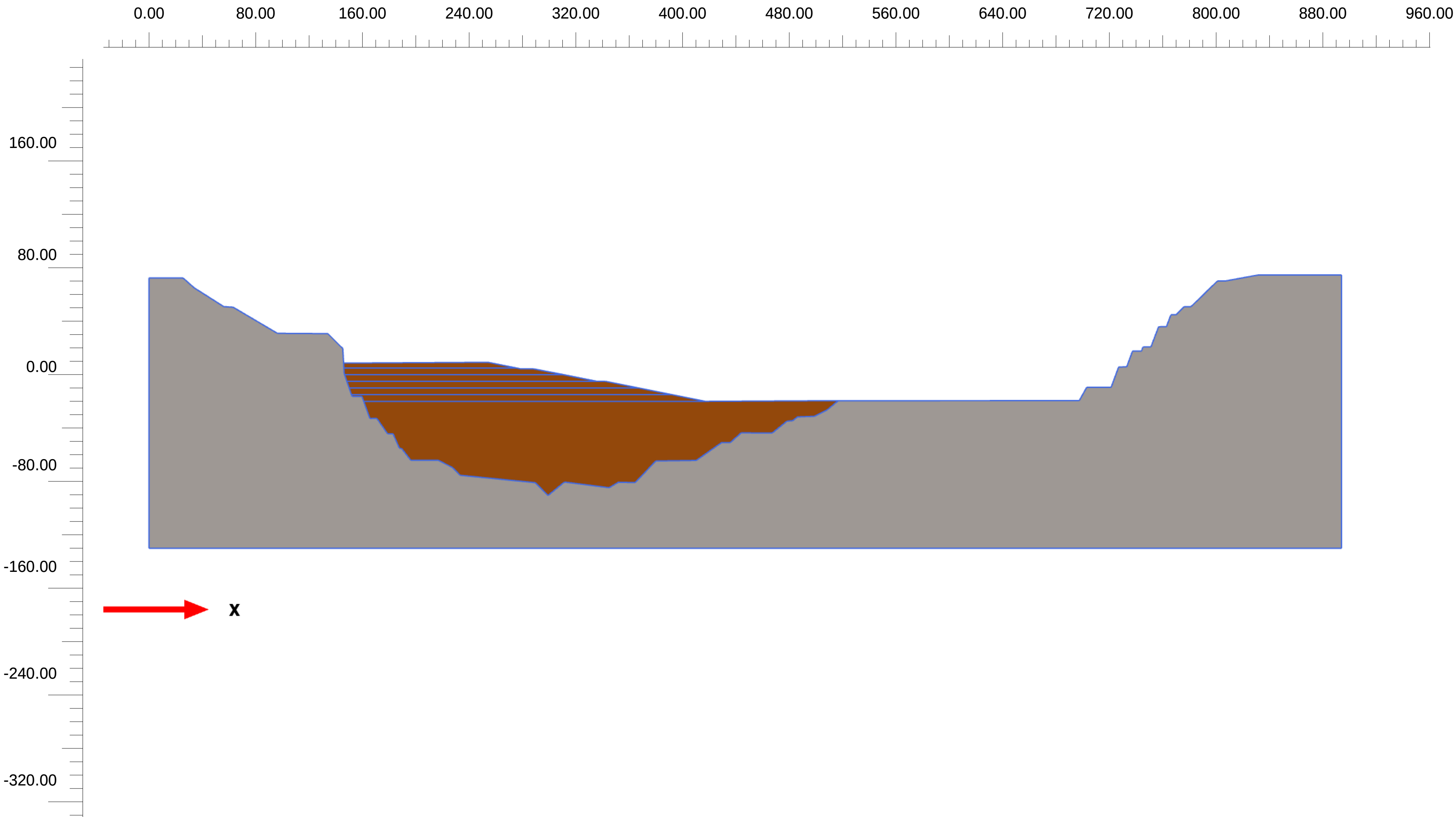
sirius Environmental	*Project description* Croft Quarry - Restoration Infill to 10mAOD		*Date* 13/01/2022
	Project filename Croft Quarry - Restoration Infill	*Step* 157	*Company* Sirius Environmental Ltd

Step info				
Phase	L6S [Phase_8]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-0.9771E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.04124E-3	ΣM_{sf}	1.029
Time	Increment	0.000	End time	8578
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	1.000
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	392.5 kN/m^2			

APPENDIX SRA4

1 IN 5 SLOPE GRADIENT PLAXIS PRINTOUTS

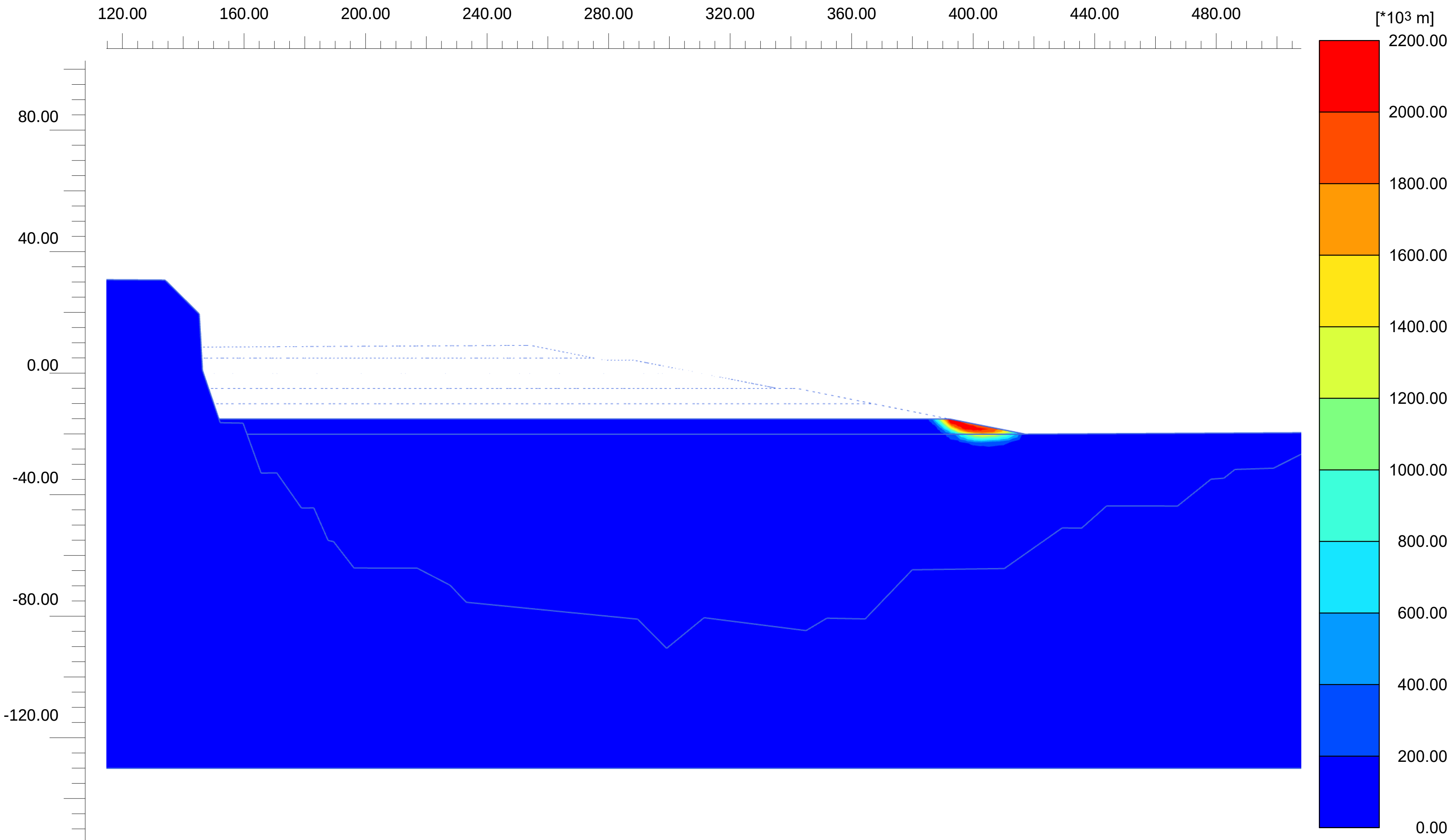
Output Version 21.1.0.479



Connectivity plot

Project description			*Date*
Croft Quarry - Restoration Infill 1 in 5 Geometry			13/01/2022
Project filename	*Step*	*Company*	
Croft Quarry - Restoration ...	61	Sirius Environmental Ltd	

Output Version 21.1.0.479



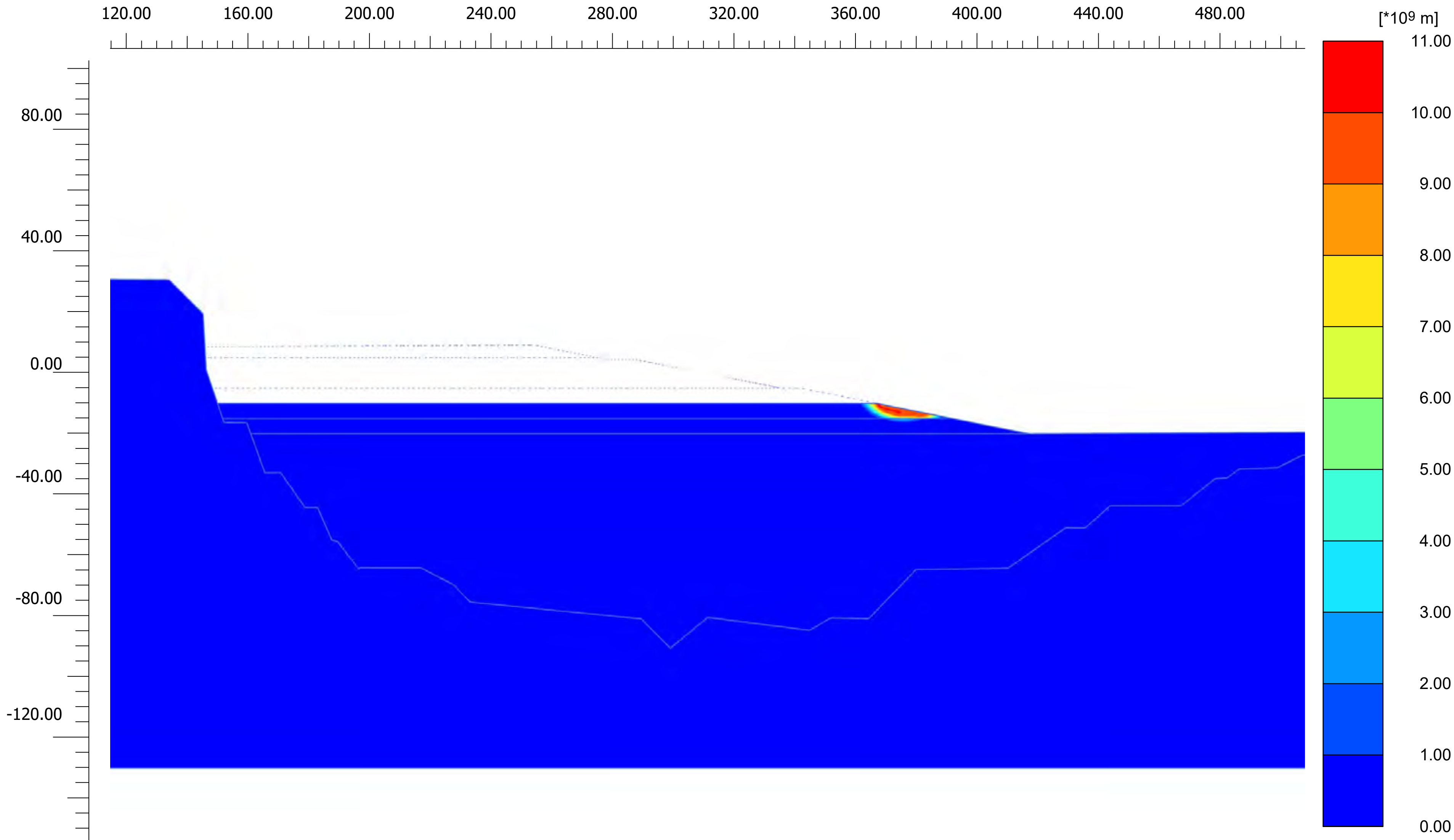
Incremental displacements |Δu| (scaled up $0.0100*10^{-3}$ times)

Maximum value = $2.182*10^{6}$ m (Element 515 at Node 7244)

Project description			Date
Croft Quarry - Restoration Infill to -15mAOD			13/01/2022
Project filename	Step	Company	
Croft Quarry - Restoration ...	661	Sirius Environmental Ltd	

Sirius Environmental

Step info				
Phase	L1S [Phase_13]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-0.01351E-12			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.07374E-3	ΣM_{sf}	1.990
Time	Increment	0.000	End time	6753
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9664
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	491.7 kN/m^2			



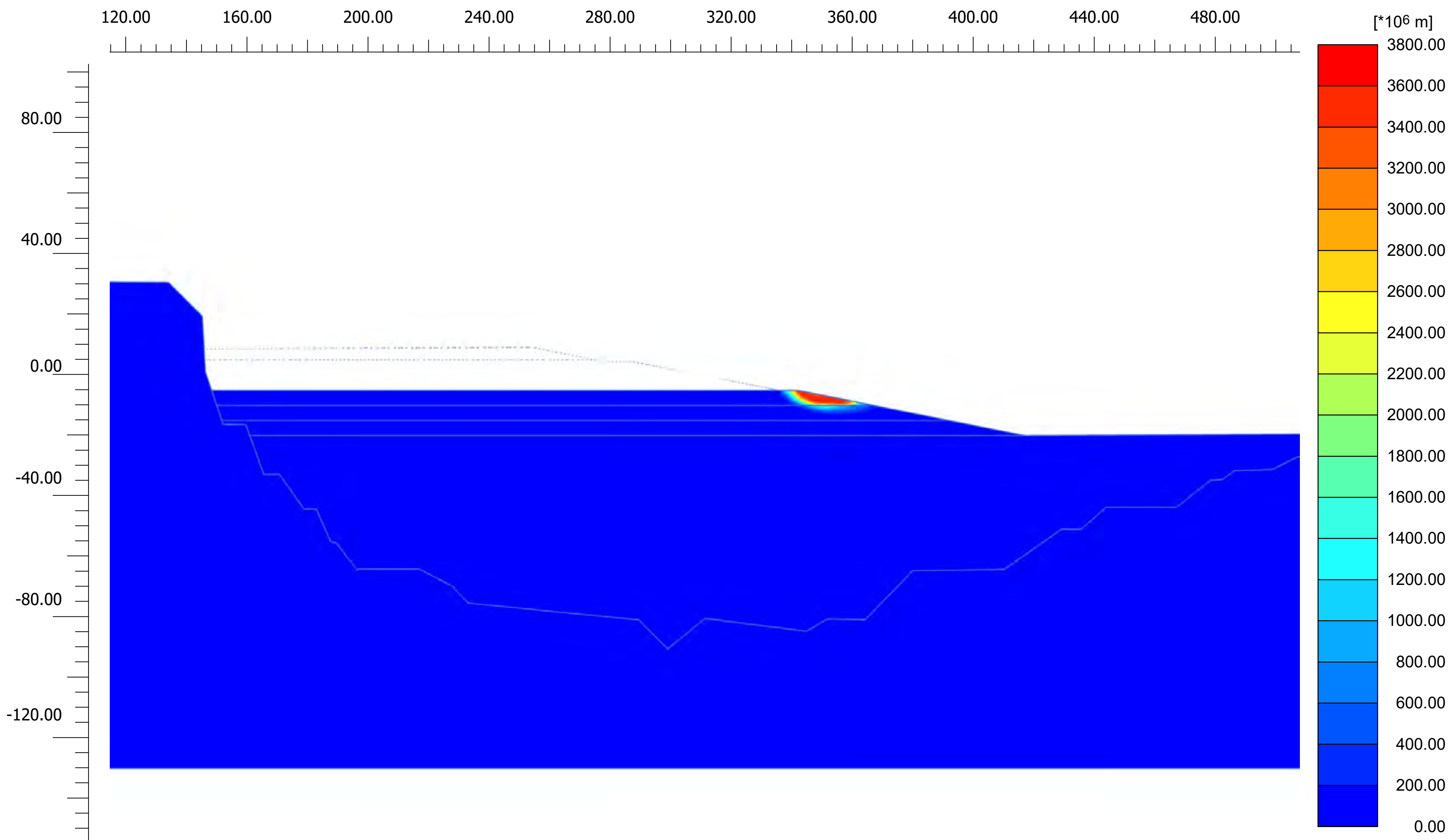
Incremental displacements |Δu| (scaled up $2.00*10^{-9}$ times)

Maximum value = $10.41*10^{9}$ m (Element 415 at Node 6986)

Sirius Environmental	*Project description* Croft Quarry - Restoration Infill		*Date* 13/01/2022
	Project filename Croft Quarry - Restoration ...	*Step* 561	*Company* Sirius Environmental Ltd

Step info				
Phase	L2S [Phase_12]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.09363E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.4056E-3	ΣM_{sf}	1.461
Time	Increment	0.000	End time	7118
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9754
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	351.6 kN/m^2			

Output Version 21.1.0.479



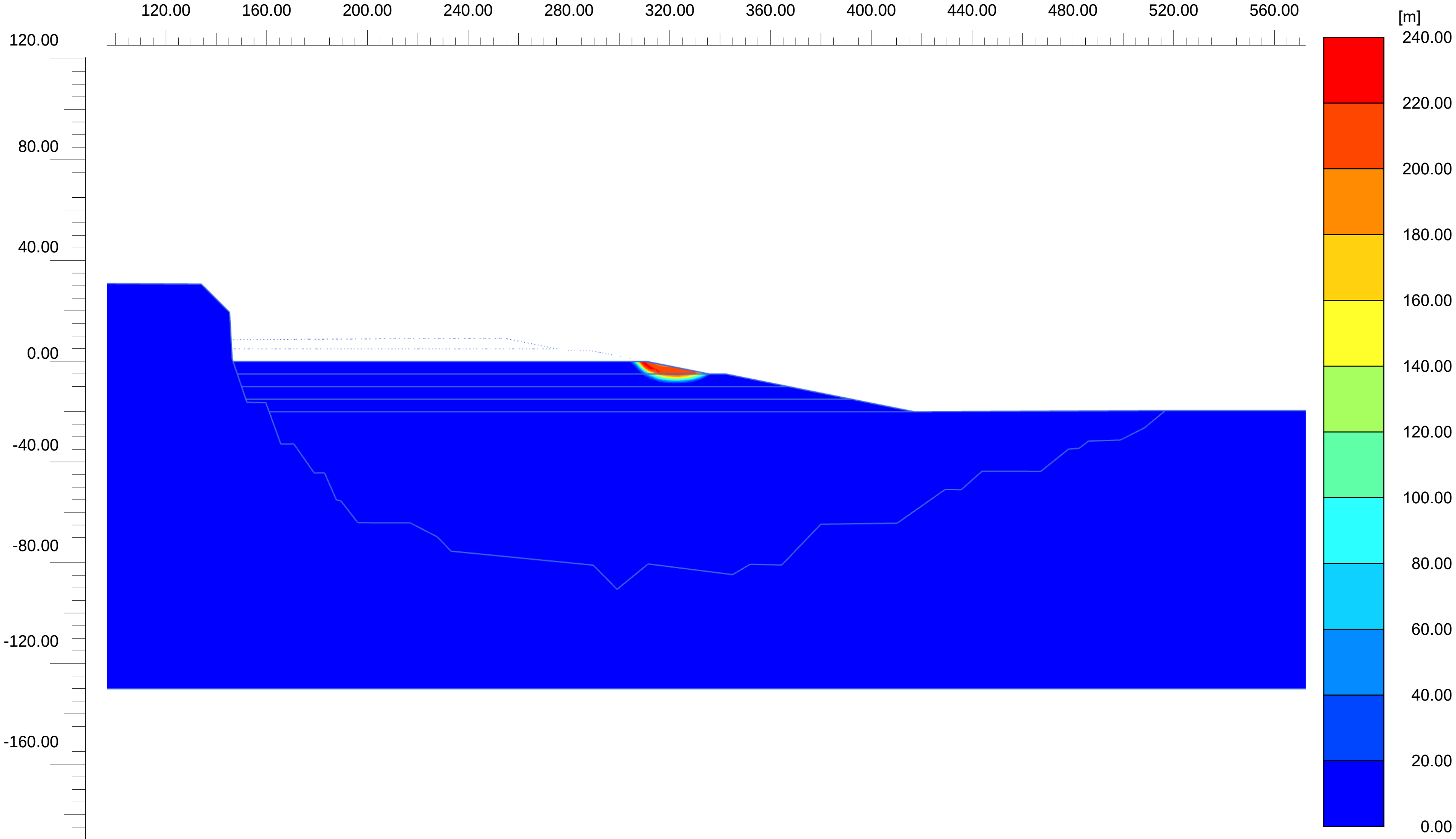
Incremental displacements |Δu| (scaled up $5.00*10^{-9}$ times)

Maximum value = $3.636*10^{9}$ m (Element 356 at Node 6176)

Project description		*Date*
Croft Quarry - Restoration Infill to -5mAOD		13/01/2022
Project filename	*Step*	*Company*
Croft Quarry - Restoration ...	461	Sirius Environmental Ltd

Step info				
Phase	L3S [Phase_11]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-0.02362E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.05075E-3	ΣM_{sf}	1.278
Time	Increment	0.000	End time	7483
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9835
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	316.9 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 0.100 times)

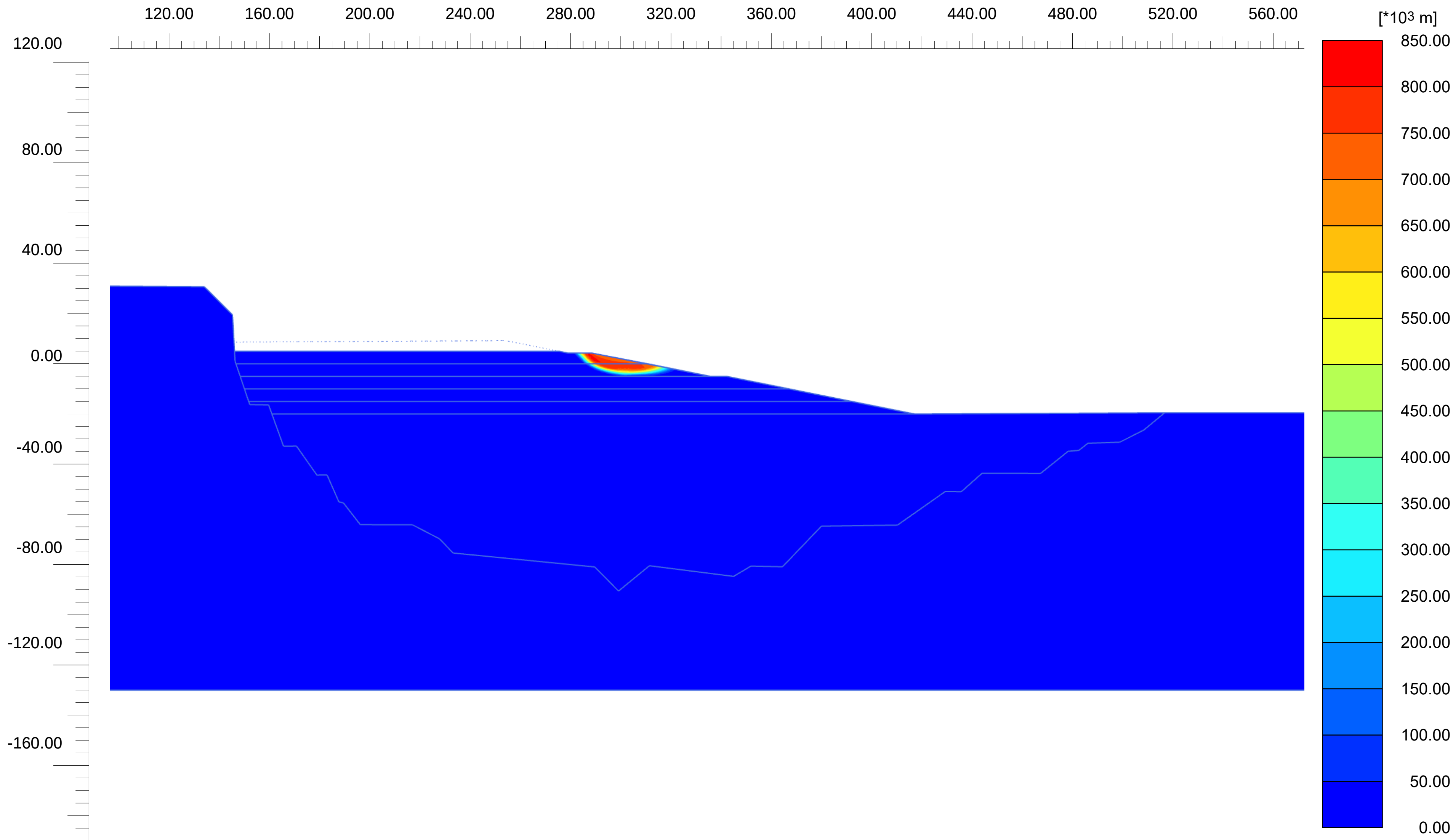
Maximum value = 225.5 m (Element 268 at Node 3537)

Project description	Date
Croft Quarry - Restoration Infill to 0mAOD	20/01/2022

Project filename	Step	Company
Croft Quarry - Restoration ...	361	Sirius Environmental Ltd

Step info				
Phase	L4S [Phase_10]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	1.616E-9			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.2154E-3	ΣM_{sf}	1.219
Time	Increment	0.000	End time	7863
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9904
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	2280 kN/m^2			

Output Version 21.1.0.479



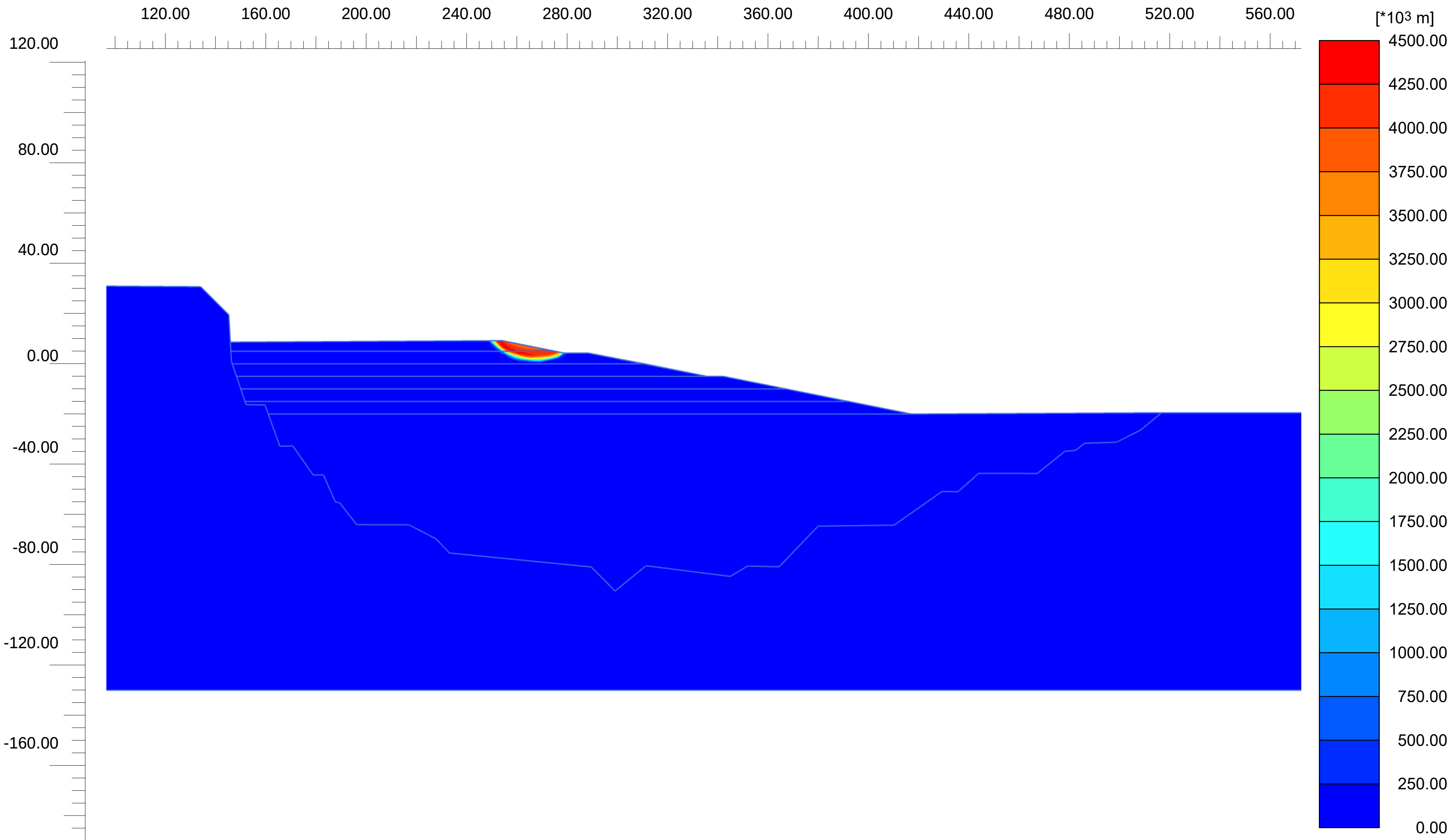
Incremental displacements |Δu| (scaled up 0.0500*10^{-3} times)

Maximum value = 824.2*10^{3} m (Element 72 at Node 3645)

sirius Environmental	*Project description* Croft Quarry - Restoration Infill to 5mAOD		*Date* 20/01/2022
	Project filename Croft Quarry - Restoration ...	*Step* 261	*Company* Sirius Environmental Ltd

Step info				
Phase	L5S [Phase_9]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.01523E-12			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.03238E-3	ΣM_{sf}	1.241
Time	Increment	0.000	End time	8223
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9963
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	5830 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up $5.00*10^{-6}$ times)

Maximum value = $4.400*10^{6}$ m (Element 8 at Node 6713)

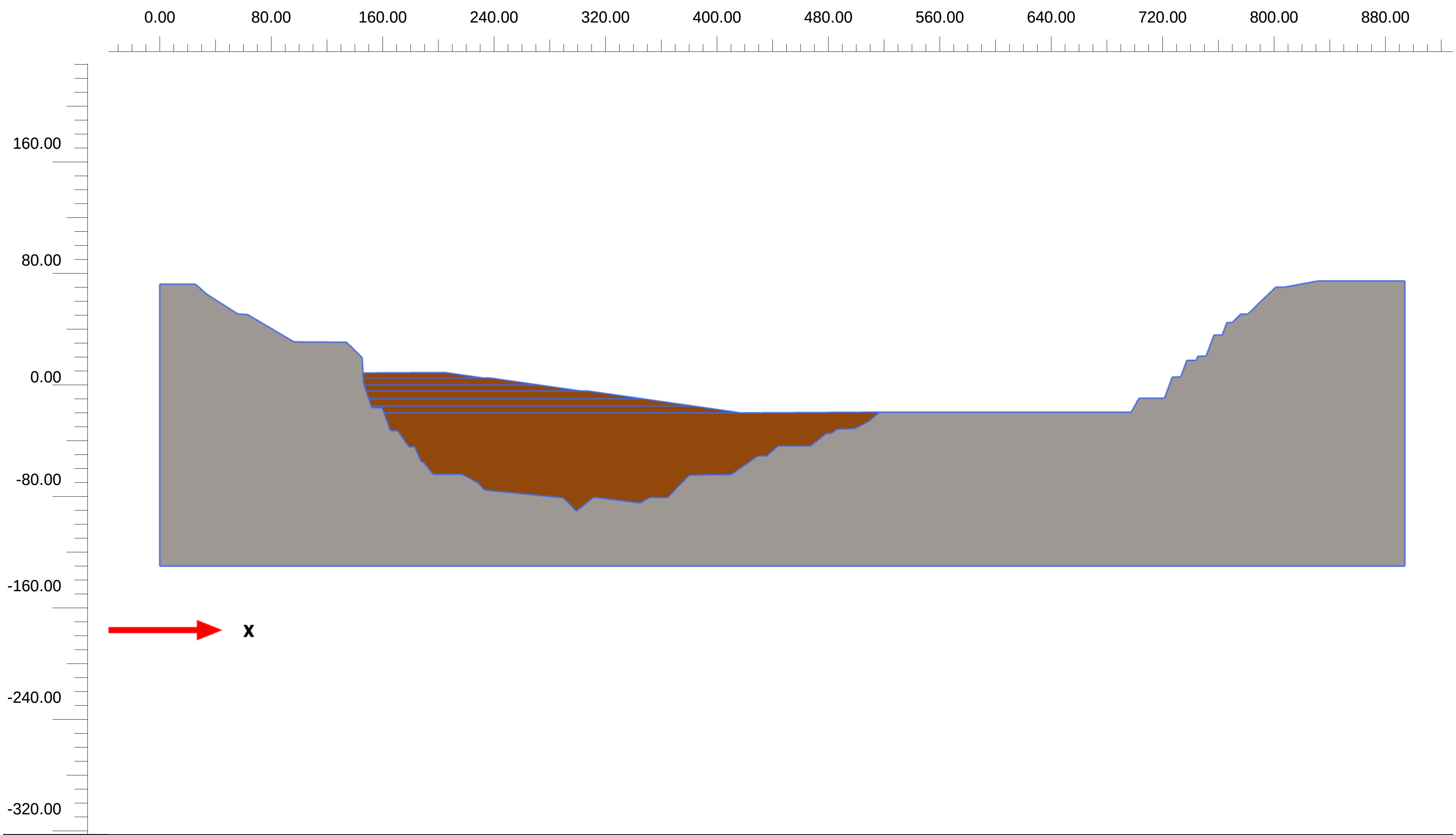
Project description Croft Quarry - Restoration Infill to 10mAOD			*Date* 20/01/2022
Project filename Croft Quarry - Restoration ...	*Step* 161	*Company* Sirius Environmental Ltd	

Step info				
Phase	L6S [Phase_8]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	-0.2727E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.07532E-3	ΣM_{sf}	1.204
Time	Increment	0.000	End time	8578
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	1.000
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	510.0 kN/m^2			

APPENDIX SRA5

1 IN 7 SLOPE GRADIENT PLAXIS PRINTOUTS

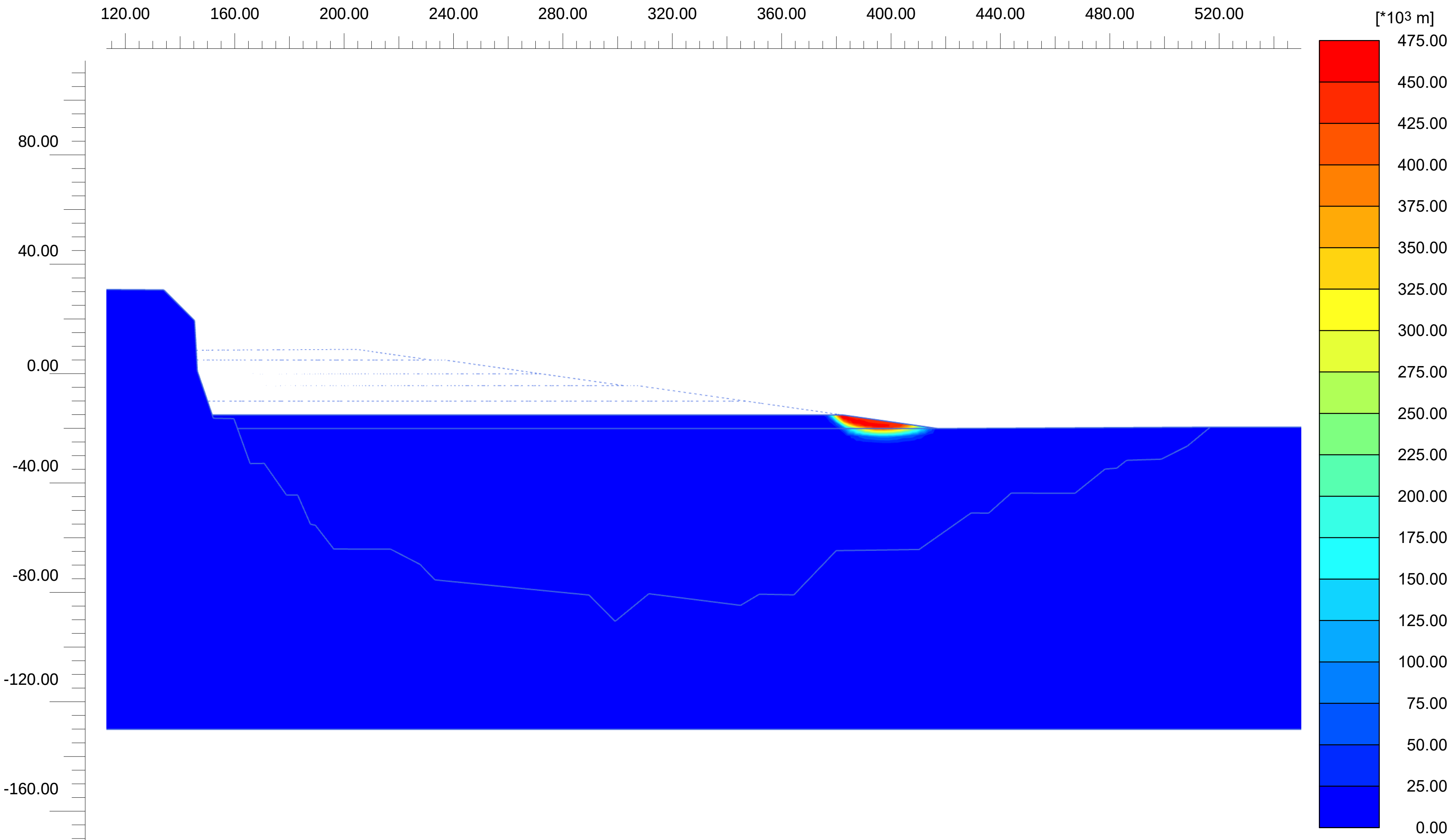
Output Version 21.1.0.479



Connectivity plot

Project description		*Date*
Croft Quarry - Restoration Infill 1 in 7 Geometry		13/01/2022
Project filename	*Step*	*Company*
Croft Quarry - Restoration ...	50	Sirius Environmental Ltd

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 0.0500*10^{-3} times)

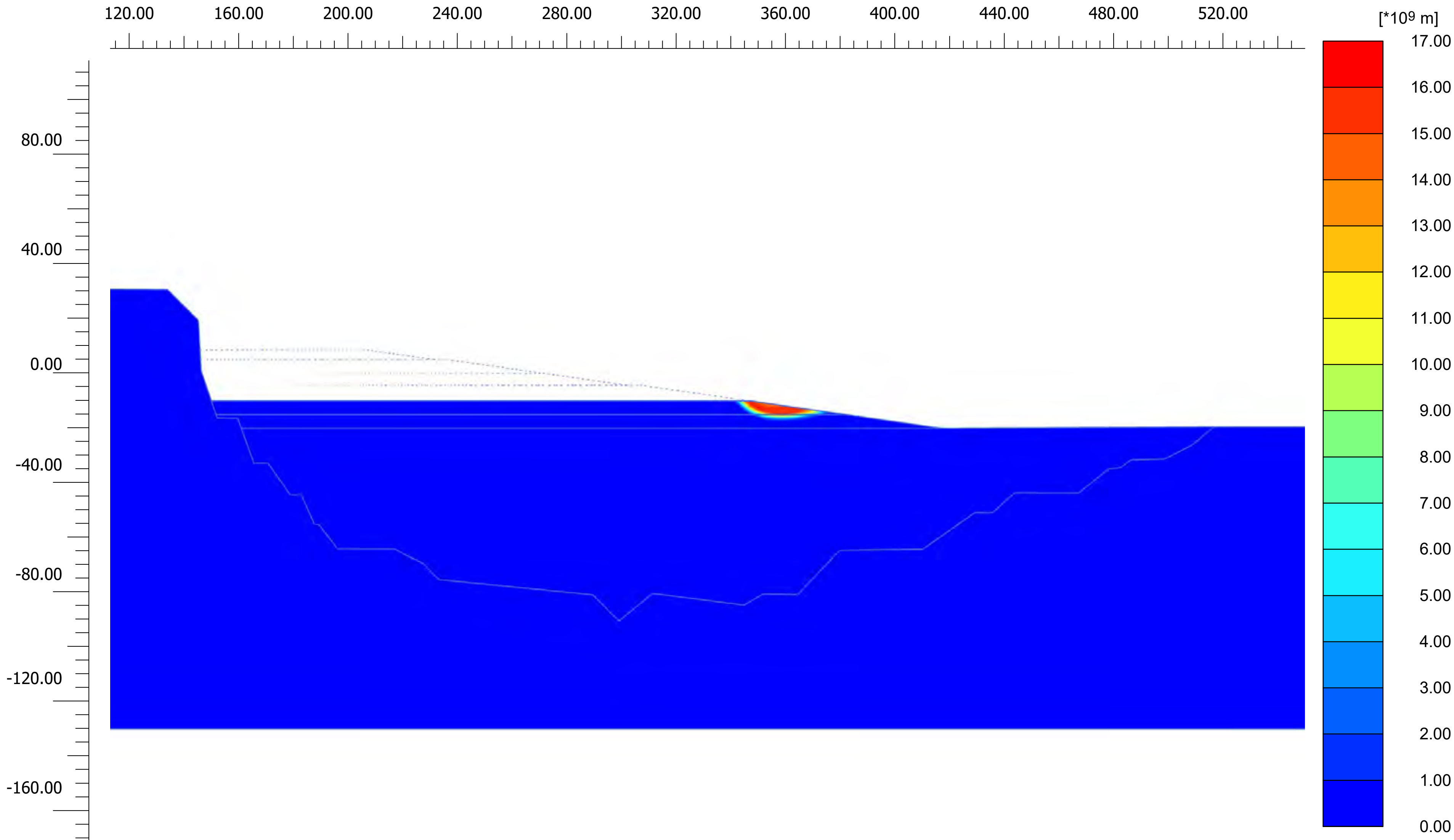
Maximum value = 472.1*10^{3} m (Element 319 at Node 1639)

Project description	Date
Croft Quarry - Restoration Infill to -15mAOD	13/01/2022

Project filename	Step	Company
Croft Quarry - Restoration ...	650	Sirius Environmental Ltd

Step info				
Phase	L1S [Phase_13]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-5.455E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.1150E-3	ΣM_{sf}	2.346
Time	Increment	0.000	End time	6753
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9723
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	606.8 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up $2.00*10^{-9}$ times)

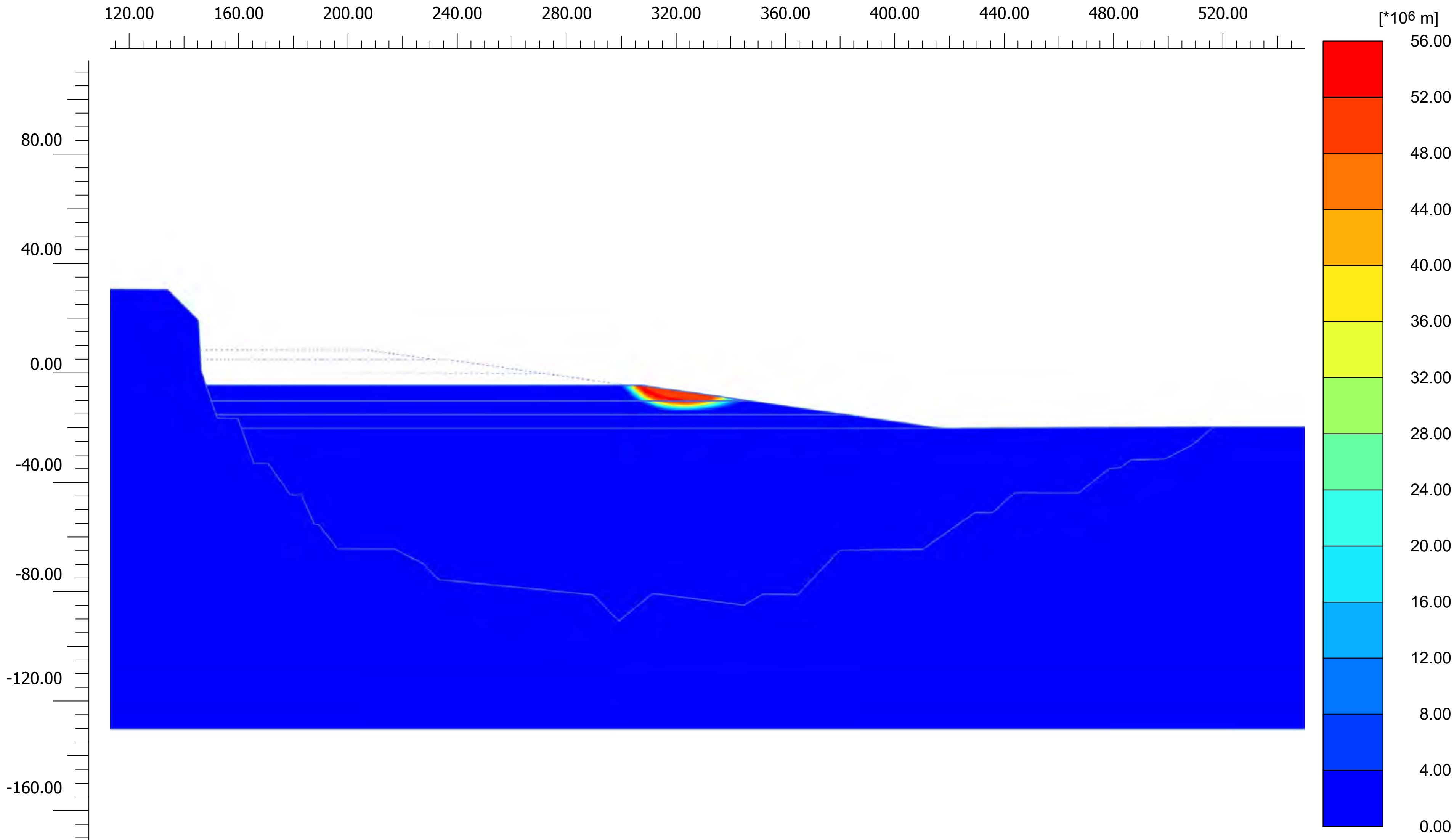
Maximum value = $16.32*10^{9}$ m (Element 241 at Node 1702)

Project description	*Date*
Croft Quarry - Restoration Infill to -10mAOD	13/01/2022

Project filename	*Step*	*Company*
Croft Quarry - Restoration ...	550	Sirius Environmental Ltd

Step info				
Phase	L2S [Phase_12]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.06479E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.05814E-3	ΣM_{sf}	1.710
Time	Increment	0.000	End time	7118
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9807
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	588.9 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 0.500×10^{-6} times)

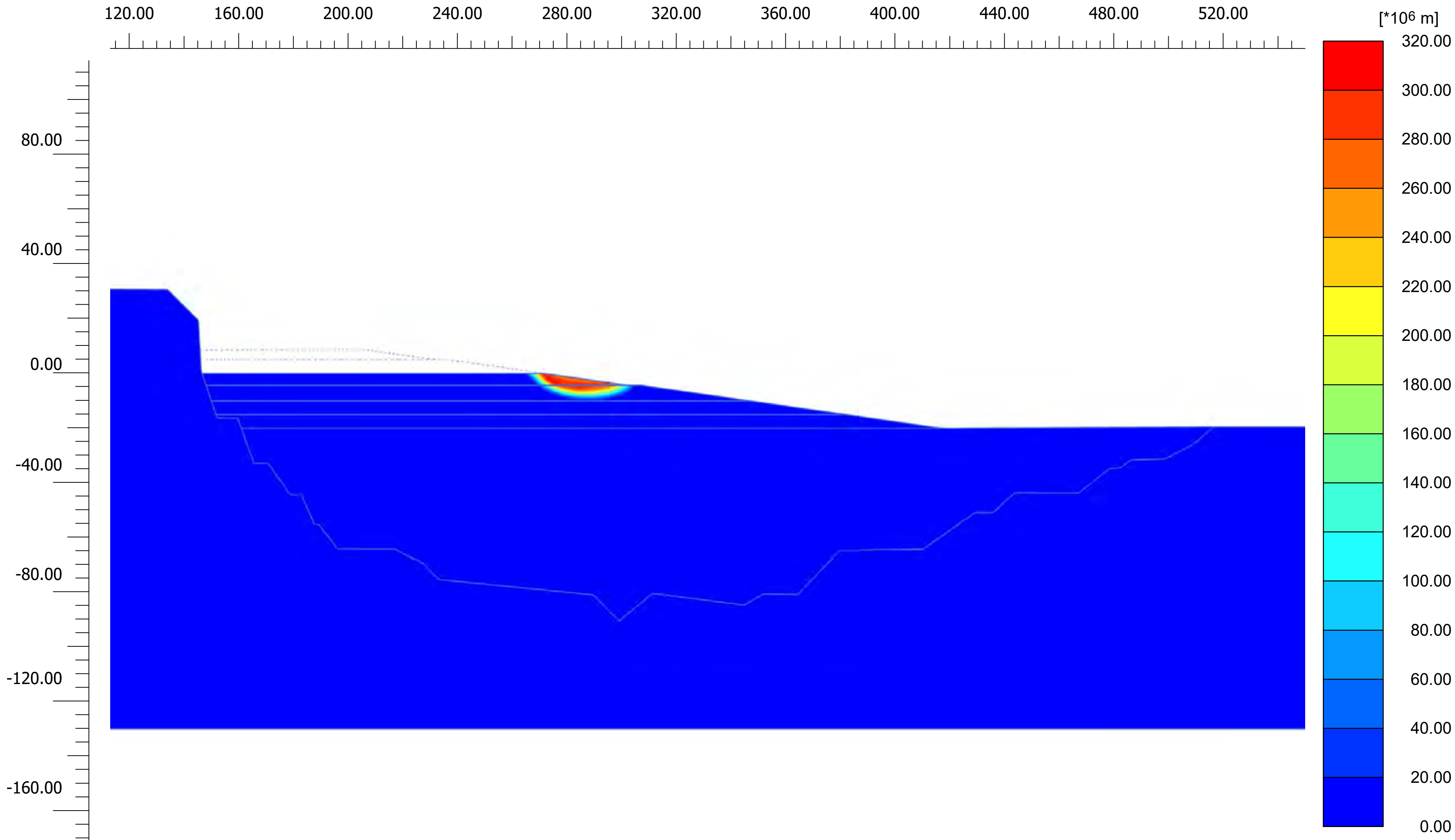
Maximum value = 55.57×10^{6} m (Element 178 at Node 2389)

Project description		Date
Croft Quarry - Restoration Infill to -5mAOD		13/01/2022
Project filename	*Step*	*Company*
Croft Quarry - Restoration ...	450	Sirius Environmental Ltd

Sirius Environmental

Step info				
Phase	L3S [Phase_11]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	-0.1024E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.07560E-3	ΣM_{sf}	1.317
Time	Increment	0.000	End time	7428
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9887
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	355.7 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up 0.0500*10^{-6} times)

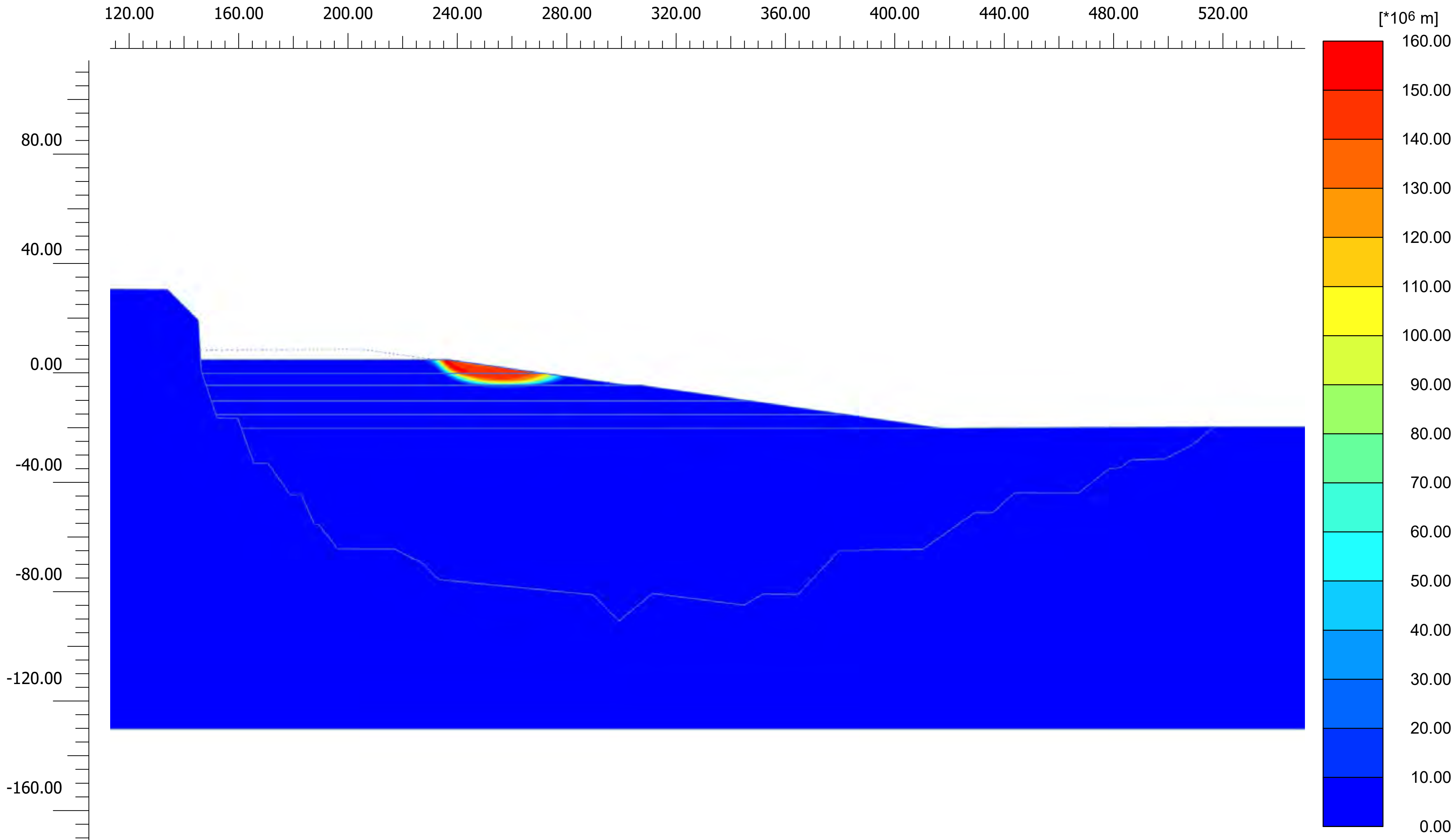
Maximum value = 308.6*10^{6} m (Element 83 at Node 3386)

Project description	Date
Croft Quarry - Restoration Infill to 0mAOD	13/01/2022

Project filename	Step	Company
Croft Quarry - Restoration ...	350	Sirius Environmental Ltd

Step info				
Phase	L4S [Phase_10]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-8.415E-18			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.3192E-3	ΣM_{sf}	1.338
Time	Increment	0.000	End time	7728
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9935
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	432.9 kN/m^2			

Output Version 21.1.0.479



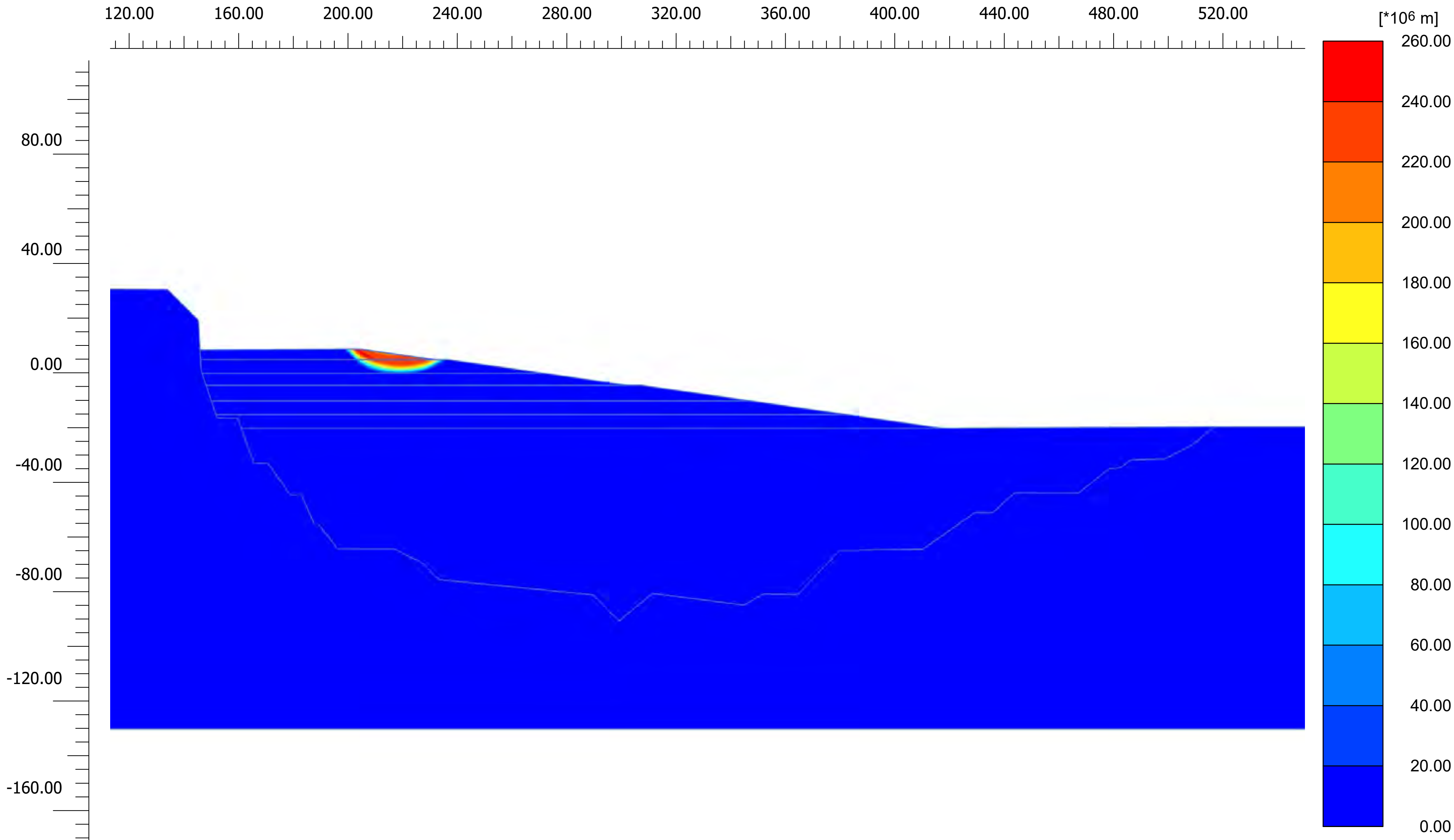
Incremental displacements |Δu| (scaled up $0.200*10^{-6}$ times)

Maximum value = $154.8*10^{6}$ m (Element 45 at Node 5124)

	Project description Croft Quarry - Restoration Infill to 5mAOD		*Date* 13/01/2022
Sirius Environmental	*Project filename* Croft Quarry - Restoration ...	*Step* 250	*Company* Sirius Environmental Ltd

Step info				
Phase	L5S [Phase_9]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	1.055E-18			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.2232E-3	ΣM_{sf}	1.315
Time	Increment	0.000	End time	8093
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9978
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	331.2 kN/m^2			

Output Version 21.1.0.479



Incremental displacements |Δu| (scaled up $0.100*10^{-6}$ times)

Maximum value = $245.0*10^{6}$ m (Element 10 at Node 6991)

Project description		Date
Croft Quarry - Restoration Infill to 10mAOD		13/01/2022

Project filename	Step	Company
Croft Quarry - Restoration ...	150	Sirius Environmental Ltd

Step info				
Phase	L6S [Phase_8]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	-0.1302E-15			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.04794E-3	ΣM_{sf}	1.682
Time	Increment	0.000	End time	8458
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	1.000
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	502.3 kN/m^2			