A417 Missing Link
TR010056

6.4 Environmental Statement
Appendix 9.2 Preliminary Ground Investigation report

Planning Act 2008

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The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

A417 Missing Link

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6.4 Environmental Statement
Appendix 9.2 Preliminary Ground Investigation report

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Executive summary

This Preliminary Ground Investigation Report (GIR) has been prepared to inform the PCF Stage 3 Environmental Statement and PCF Stage 3 design of the A417 Missing Link (the scheme). The document has been prepared in accordance with the Design Manual for Roads and Bridges (DMRB) CD622 – Managing Geotechnical Risk – Revision 1 March 2020.

All available geotechnical information including site walkovers, geological mapping, geomorphological mapping, historical and current phases of ground investigation (GI) and published information have been presented. The report refers to the Preliminary Sources Study Report (PSSR) produced as part of PCF Stage 2, providing an update to the issues identified where further information has become available. An updated geotechnical risk register is presented, considering ground investigations undertaken and assessments made, and based on the PCF Stage 3 designs that have been developed.

The following provides a brief summary on the contents and main findings of this GIR:

Section 1 and 2 provide a background and high-level description to the scheme and presents the scope and objectives of this GIR. The PCF Stage 3 scheme arrangement has been referenced in this GIR. Figures showing the locations of all GI undertaken, including geophysical surveys and exploratory hole locations are presented. Geological long sections along the centreline of the scheme based on the available GI data are also presented.

Section 3 summarises the existing information used to inform the report additional to that presented in the PSSR, with reference to more detailed information included as a series of Appendices. A summary of the Phase 1 ground investigation conducted at PCF Stage 2 is presented.

Section 4 summarises the GI conducted during PCF Stage 3 (termed the Phase 2A GI). Completion of the Phase 2A GI was still ongoing at the time of writing the GIR. A further investigation is proposed to support the next stage of design as set out in the Annex A Addendum. Both phases of ground investigation will be reported in an update to this GIR, which will be prepared in the next stage of design.

Section 5 is a summary of the ground conditions encountered across the scheme based on the interpretation of the available data. A ground model is presented, and commentary provided to highlight where differences to the published data have been identified.

The ground investigations have generally confirmed the published geological units anticipated across the scheme as follows:

- Made Ground – predominantly along Crickley Hill (Ch 0+700 to Ch 1+700)
- Cheltenham Sands and Gravels (Ch 0+000 to Ch 0+500)
- Mass movement deposits (Ch 0+500 to Ch 1+750 (Crickley Hill) and Ch 3+100)
- Head or completely weathered rock (Ch 1+750 to Ch 5+500)
- Great Oolite Group split into:
    - The limestone of the White Limestone and Hampen Formations (Ch 2+950 to Ch 3+500 and sporadically from Ch 3+500 to Ch 5+500)
    - The Fuller's Earth Formation (Ch 2+900 to Ch 5+500)
- Inferior Oolite Group (including the Aston Limestone Formation, Salperton Limestone Formation and the Birdlip Limestone Formation) (Ch 1+750 to Ch 5+500 but exposed beneath the Scheme from Ch 1+750 to Ch 2+920)
- Lias Group split into:
    - The Bridport Sands Formation (Ch 1+750 to Ch 2+500 and Ch 3+500 to Ch 5+500)
    - Lias Group mudstones (Ch 0+000 to Ch 1+700)

Section 5 provides further detail on the materials identified during the ground investigations including descriptions, encountered depths and thicknesses. For each of the identified material types, ranges of geotechnical parameters in addition to average values. On completion of the Phase 2A GI and further ground investigation the review of parameters will be updated in the next stage of design to present appropriate characteristic values.

Differences to the published geological information include changes to the positions of mapped geological faults, including the Shab Hill Barn Fault and the Stockwell Fault, and the identification of a new fault, which is referred to as the 'Churn Valley Fault'. Changes to the mapped stratigraphy include more extensive exposures of the Fuller's Earth Formation to the south of Shab Hill.

Section 5 includes a summary of the main geomorphological features identified across the site, focusing on the Crickley Hill valley and Churn valley mass movement deposits. The geomorphological assessment has been based on historical information presented in the PSSR, together with geological field mapping, LiDAR data and GI information obtained during PCF Stage 3.

A summary of the hydrogeology for the scheme is presented, with reference to more detailed information which is appended to the GIR and the Hydrogeological Impact Assessment appended with the Environmental Statement. Findings of the groundwater monitoring and a hydrogeological conceptual model are presented. The main findings are summarised below.

- There are 3 main aquifers - the superficial deposits, the Inferior Oolite Group and the Great Oolite Group limestone formations. The Lias Group mudstones and the Fuller's Earth Formation are aquitards which form barriers to flow and influence groundwater flow within the overlying aquifer.
- Clay dominated mass movement deposits support the springs on Crickley Hill.
- There is a deep unsaturated zone in the Inferior Oolite aquifer and groundwater levels are seasonal. Karst is extensive throughout the basal formations of the aquifer and flashy groundwater responses have been recorded around Air Balloon. The Inferior Oolite Group supports springs at headwaters of the tributary of Norman's Brook.
- Groundwater levels in the Great Oolite Group limestone aquifer are seasonal and are controlled by faults which allow groundwater leakage into the underlying IOG aquifer. The Great Oolite Group limestone aquifer does not include any karst features.

An assessment of ground aggressivity to buried concrete, based on laboratory testing of soil and groundwater obtained during the Phase 1 and Phase 2A GI, is presented. This assessment has indicated the presence of elevated sulfates and sulfides within the Crickley Hill mass movement deposits, the Fuller's Earth Formation and the Lias Group (Bridport Sands Formation and Lias Group mudstones. Recommendations are made for appropriate measures that should be adopted to protect buried concrete form chemical attack as a result of the aggressive ground conditions identified.

The results of chemical testing of soil and groundwater undertaken during the Phase 1 and Phase 2A GIs are presented. Tier 1 and Tier 2 assessments of potential impacts on human health and the environment are presented. These assessments have not identified any unacceptable risks with respect to the scheme end users. The completed risk assessments identified several exceedances within analysed samples of groundwater and surface water. The exceedances in groundwater are not considered significant and the surface water testing results do not indicate that the groundwater currently has a detrimental impact on surface water quality. Six areas of concern have been identified that require further assessment to confirm the source of contamination and the associated risks. Commentary is provided on material reuse, disposal, remediation and unexpected contamination.

Section 6 presents the geotechnical risk register that has been appended to the GIR. An update and amendment of the geotechnical risk register presented in the PSSR is included. The risk register has been used to:

- identify or modify any previously identified risks and add any additional risks identified.
- record further actions to mitigate these risks during subsequent stages of the scheme (design, construction and operation).

Section 7 of the report presents an engineering assessment, which includes consideration of earthworks (cuttings and embankments), drainage, pavement design and structure foundations and retaining walls.

A qualitative assessment of the hazards and consequent risks posed by the marginally stable mass movement deposits on the wider slopes of the Crickley Hill valley is presented. It has been concluded that future slope movements are likely to be triggered by increased pore water pressures within the slopes during and following extreme rainfall events. Mitigation in the form of horizontal drainage has been proposed to control groundwater levels and limit pore water pressures during such events.

The PCF Stage 2 PSSR classified that geotechnical category of the scheme as Geotechnical Category 3. Based on the information presented in this report, it is proposed that the geotechnical category of the scheme is generally amended to Geotechnical Category 2. However, given the relative complexity of the ground conditions in the vicinity of Crickley Hill, it is recommended that the slope stabilisation measures required for the carriageway and adjacent slopes to the north between Ch 0+500 to Ch 1+700 remain at Geotechnical Category 3.

1 Introduction

1.1 Purpose of this document

1.1.1 This Preliminary Ground Investigation Report (GIR) has been prepared to inform the PCF Stage 3 Environmental Statement and PCF Stage 3 design of the A417 Missing Link (the scheme). This report presents a summary and initial interpretation of the available information gathered in relation to the ground and groundwater conditions along the scheme. The report has been prepared in accordance with the requirements of CD622 [1].

1.1.2 The recent ground investigation scoped to support the preliminary design has been termed Phase 1 and Phase 2A. Two factual reports [2] and [3] have been produced for each phase of GI. Completion of the Phase 2A GI was ongoing at the time of writing this GIR and a further investigation to support detailed design, as defined in the Annex A Addendum [4] is to be undertaken post issue of this GIR. Both these phases of GI will be reported as an update to this GIR as part of the next stage of the design.

1.2 Scheme overview

1.2.1 The A417/A419 is a strategic route between Gloucester and Swindon that provides an important link between the Midlands/North and South of England. The route is an alternative to the M5/M4 route via Bristol. The section of the A417 near Birdlip, known as the 'Missing Link', forms the only section of single carriageway along the route and is located in the Cotswolds Area of Outstanding Natural Beauty (AONB).

1.2.2 In 2014, the Department for Transport (DfT) announced its five-year investment programme for making improvements to the Strategic Road Network (SRN) across England. This scheme is one of more than 100 schemes identified as part of the first Road Investment Strategy (RIS1) 2015-2020[i]. Funding for delivery of the scheme has been confirmed within the second Road Investment Strategy (RIS2)[ii], which covers the period between 2020 and 2025 which was published on 11 March 2020.

1.2.3 This scheme to upgrade this section of the A417 to dual carriageway, in a way that is sensitive to the surrounding AONB, would help unlock Gloucestershire's potential for growth, support regional plans for more homes and jobs, and improve life in local communities.

1.3 Scheme vision and objectives

1.3.1 The scheme vision is for a landscape-led highways improvement scheme that will deliver a safe and resilient free-flowing road whilst conserving and enhancing the special character of the Cotswolds AONB; reconnecting landscape and ecology; bringing about landscape, wildlife and heritage benefits, including enhanced visitors' enjoyment of the area; improving local communities' quality of life; and contributing to the health of the economy and local businesses.

[i] Department for Transport (March 2015), Road investment strategy: 2015 to 2020, Accessed 29 January 2020, https://www.gov.uk/government/publications/road-investment-strategy-for-the-2015-to-2020-road-period
[ii] Department for Transport (March 2020), Road investment strategy: 2020 to 2025, Accessed 11 March 2020, https://www.gov.uk/government/publications/road-investment-strategy-2-ris2-2020-to-2025

1.3.2 In order to deliver this vision, the following scheme objectives have been set:

- **Safe, resilient and efficient network:** to create a high-quality resilient route that helps to resolve traffic problems and achieves reliable journey times between the Thames Valley and West Midlands as well as providing appropriate connections to the local road network.
- **Improving the natural environment and heritage:** to maximise opportunities for landscape, historic and natural environment enhancement within the Cotswolds AONB and to reduce negative impacts of the proposed scheme on the surrounding environment.
- **Community & access:** to enhance the quality of life for local residents and visitors by reducing traffic intrusion and pollution, discouraging rat-running through villages and substantially improving public access for the enjoyment of the countryside.
- **Supporting economic growth:** to facilitate economic growth, benefit local businesses and improve prosperity by the provision of a free flowing road giving people more reliable local and strategic journeys.

1.4 Scheme description

1.4.1 The scheme would provide 3.4 miles (5.5km) of new, rural all-purpose dual carriageway for the A417. The new dual carriageway would connect the existing A417 Brockworth bypass with the existing dual carriageway A417 south of Cowley. The new dual carriageway would be completed in-line with current trunk road design standards. The section to the west of the existing Air Balloon roundabout would follow the existing A417 corridor, but to the south and east of the Air Balloon roundabout, the corridor would be offline, away from the existing road corridor.

1.4.2 The project would include a new crossing near Emma's Grove for walkers, cyclists and horse riders including disabled users, which would accommodate the Cotswold Way National Trail. A new junction would be incorporated at Shab Hill, providing a link from the A417 to the A436 (towards the A40 and Oxford), and to the B4070 (for Birdlip and other local destinations).

1.4.3 A new 37m wide multi-purpose crossing to provide essential mitigation for bats and enhancement opportunity of ecology and landscape integration. The public will also further benefit as the crossing would accommodate the Gloucestershire Way and provide an improved visitor experience.

1.4.4 A new junction would be included near Cowley, replacing the existing Cowley roundabout, making use of an existing underbridge to provide access to local destinations. The use of the existing underbridge would allow for all directions of travel to be made.

1.4.5 The existing A417 between the existing 'Air Balloon roundabout' and 'Cowley roundabout' would be detrunked for its entire length. Some lengths of the existing road would be converted into a route for walkers, cyclists and horse riders including disabled users. Other sections would be retained as lower-class public roads, maintaining local access for residents. Some of the route would provide common land.

2 Scope and objectives

2.1 Scope and objective of the report

2.1.1 The objective of the preliminary Ground Investigation Report (GIR) is to identify and suitably manage the geotechnical risks associated with the project.

2.1.2 Reference is made to two factual reports that have been produced by the specialist ground investigation contractor [2] [3], which contains all of the factual information and test results. This GIR includes a geotechnical evaluation of the information, stating the assumptions made in the interpretation of the information and test results and known limitations of the results.

2.1.3 This report should be read alongside the following drawings presented in Appendix J.

- Exploratory Hole Location Plan (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000001 to -000006)
- Geological Long Sections (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010)

2.2 Geotechnical category

2.2.1 The Preliminary Sources Study Report (PSSR) undertaken in PCF Stage 2 in 2018 [5] classified the project as Geotechnical Category 3 in accordance with the guidelines stipulated in HD22/08.

2.2.2 The project is generally classified as Geotechnical Category 2 in accordance with the guidelines stipulated in CD 622 [1].

2.2.3 Slope stability issues have been identified around the Crickley Hill valley and adjacent slopes to the north between chainage (Ch) 0+500 to Ch 1+700. As such, this extent of the scheme is classified as Geotechnical Category 3. (Further details are presented in Chapter 7 of this GIR with respect to the ground conditions encountered and the proposed engineering across the scheme).

3 Existing Information

3.1 General

3.1.1 The PSSR [5] produced in PCF Stage 2 in 2018 considered two route options; option 12 and option 30. Option 30 has since been selected as the favoured route alignment. As such, the intent is not to repeat the findings of the PSSR. Only desk-based information that is additional to that presented in the PSSR is presented in the following section.

3.1.2 This GIR makes reference to the information presented in the PSSR [5] to supplement the findings of the ground investigations and further assessments undertaken. Where additional information has been identified following site walkover assessments, geomorphological mapping and intrusive and geophysical investigations which allow the assessments in the PSSR to be further developed, this is discussed within this GIR and the supporting Appendices.

3.2 Topographical maps

3.2.1 From Ch 0+000 to Ch 0+500 the proposed route is on relatively flat low-lying land (~90m AOD). Between Ch 0+500 and Ch 2+100 the proposed route follows the existing A417 east, rising up through a valley, on to the Cotswold escarpment (290m AOD). The valley is asymmetrical, sloping more steeply on the northern side. This section of the alignment which rises up to the Cotswold escarpment is known as Crickley Hill.

3.2.2 The ground plateaus on the top of the escarpment, broadly following the regional dip of the underlying limestone beds (2 to 5 degrees east-south-east) to the end of the scheme at Ch 5+500. Between Ch 3+100 and Ch 3+300, the proposed alignment crosses a shallow dry valley that slopes down to the east at which point the carriageway is to be supported on embankments up to 20m in height.

3.3 Site history

3.3.1 For a comprehensive discussion of the site history, reference should be made to the PSSR [5].

3.4 Geological maps and memoirs

3.4.1 A detailed discussion of the published geology of the site based on geological mapping, memoirs and relevant publications is presented in the PSSR [5]. The following is a brief summary of the bedrock and superficial stratigraphy for the scheme area.

Bedrock geology

3.4.2 The Jurassic rocks underlying the scheme comprise the Great Oolite Group, the Inferior Oolite Group and the Lias Group, which are further divided into formations as presented in Table 3-1.

3.4.3 Table 3-1 also presents the anticipated chainage extents where the strata are anticipated to be encountered within the scheme.

Table 3-1 Summary of bedrock geological sequence and anticipated chainage (modified from Table 4.1 of the PSSR [5])

Anticipated chainage extent	Group	Formation	Member	Typical rock type
Ch 3+500 to Ch 5+759	Great Oolite Group	White Limestone Formation	Signet Member Ardley Member Shipton Member	Limestone (including wackestones, packstones and grainstones) with mudstone and clay beds
		Hampen Formation	-	Sandy and ooidal limestone with clay and marl beds
		Fuller's Earth Formation	Eyford Member Througham Member Lower Fuller's Earth	Grey mudstone with limestone beds
Ch 1+750 to Ch 3+500	Inferior Oolite Group	Salperton Limestone Formation	Clypeus Grit Member Upper Trigonia Grit Member	Shelly, ooidal limestone including a 'hardground'
		Aston Limestone Formation	Rolling Bank Member Not grove Member Gryphite Member Lower Trigonia Grit Member	Shelly, ooidal limestone
		Birdlip Limestone Formation	Harford Member Scottsquar Member Cleeve Cloud Member Crickley Member Leckhampton Member	Ooidal, sometimes sandy limestone with sandy clay layers
Ch 0+000 to Ch 1+750	Lias Group	Bridport Sand Formation	-	Sandy mudstone and fine to very fine- grained sandstone
		Whitby Mudstone Formation	-	Mudstone with thin limestone beds at the base
		Marlstone Rock Formation	-	Ferruginous, ooidal limestone and sandstone
		Dyrham Formation	-	Silty Mudstone and Siltstone
		Charmouth Mudstone Formation	-	Mudstone with thin beds and nodules of limestone

Note: The geological groups and associated formations and members are presented in stratigraphical order (youngest to oldest) and is opposite to the direction of the scheme chainage.

3.4.4 For detailed descriptions of the bedrock likely to be encountered reference should be made to the comprehensive review presented in the PSSR [5].

3.4.5 There are a number of features related to the structural geology that have been summarised from the PSSR [5] below:

- The regional dip of the beds is between 2 and 5 degrees towards the south-east and east

- The BGS 1:50,000 geological map sheet 234 shows three faults through the project site, all trending roughly north-west south-east.
  - The most northerly of the faults, the Shab Hill Fault, is downthrown to the southwest, whilst the two faults to south; the Shab Hill Barn fault and Stockwell Fault are downthrown to the north-east
  - The downthrown block capped by the Great Oolite Group between the Shab Hill Fault and Shab Hill Barn Fault is as a graben

Superficial deposits

3.4.6 Table 3-2 summarises the superficial deposits that are anticipated to underlie the scheme.

Table 3-2 Summary of superficial deposits

Anticipated chainage extent	Superficial deposit	General comment or typical description
Various	Made Ground	Reported in the PSSR – associated with the current A417 and Grove Farm
0+500 to 1+750	Alluvium	Reported in the PSSR –likely to be associated with the tributary of Norman's Brook located along the base of the valley running up Crickley Hill
0+000 to 0+500	Cheltenham Sands and Gravels	Sand, quartzose, fine- to medium-grained, generally unbedded, with seams of poorly sorted predominantly limestone gravel, especially in the lower part. Sand probably derived by aeolian processes from nearby river terrace deposits. Gravel largely Middle Jurassic ooidal limestone derived probably by solifluction from the nearby Cotswold escarpment. (The BGS lexicon [6])
0+500 to 1+750	Mass Movement Deposits	Overlie all the area underlain by the Lias Group
3+000		Within the Churn valley at Shab Hill which is underlain by the Fuller's Earth Formation

3.4.7 The processes involved in the formation of the Mass Movement Deposits are presented in the PSSR [5] and further discussed as part of this GIR in Section 5.

3.5 Records of mines and mineral deposits

3.5.1 As stated in the PSSR [5], there was a significant amount of quarrying for the limestone of the Inferior Oolite Group between the late 16th century and the mid-1920s.

3.5.2 The BGS Britpits dataset shows a number of mineral workings in the region, primarily within the Inferior Oolite Group. There are only two on the route of the proposed alignment, which are within the valley between Ch 3+100 and Ch 3+300. Both are shown on the 1975 1:10,560 scale geological map [7]. The western one as a quarry and the eastern one as a gravel pit.

3.6 Archaeological and historical investigations

3.6.1 The PSSR [5] presents a detailed review of archaeological records near the scheme.

3.7 Previous ground investigations

Historical ground investigations

3.7.1 Several historical ground investigations (primarily carried out between 1981 to 1991) have been used to inform this GIR. The exploratory locations from the historical ground investigations are shown on the Exploratory Hole Location Plans (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000001 to -000006) presented in Appendix J. A comprehensive list and description of the historical ground investigations is presented in the PSSR [5] and is not repeated in this GIR.

3.8 Consultation with statutory bodies and agencies

Local authorities

3.8.1 Information relating to consultations with the local authorities are presented in the Consultation Report (Document Reference 5.1).

Environment Agency

3.8.2 Information relating to consultation with the Environment Agency are presented in the Consultation Report (Document Reference 5.1).

Cotswold Conservation Board

3.8.3 Information relating to consultation with the Cotswold Conservation Board are presented in the Consultation Report (Document Reference 5.1).

3.9 Flood records

3.9.1 Information relating to flood records for the scheme is presented in the Environmental Statement (ES) Chapter 13 Road drainage and the water environment (Document Reference 6.2).

3.10 Contaminated land

3.10.1 The PSSR [5] provides an overview of environmental setting(s) and potential contaminative land uses in relation to the site history for both the option 12 and option 30 scheme alignments.

3.10.2 The report concluded that: "*There is no evidence within the historical ground investigation information to suggest that there is any contaminated ground within the confines of either options 12 or 30, according to Section 78R of the Environmental Protection Act 1990. Potential areas of Made Ground have been identified and these will need investigating as part of a project specific ground investigation*."

3.10.3 As part of this GIR a contaminated land assessment has been conducted that incorporates the findings of the PSSR [5] and the current phase of ground investigation. The findings are presented in Section 5 of this report.

3.11 Other relevant information

Hydrology and hydrogeology

3.11.1 Information relating to the hydrology and hydrogeology of the scheme is presented in the PSSR [5] and the ES Appendix 13.7 Hydrogeological impact assessment (Document Reference 6.4).

Unexploded ordnance

3.11.2 The PSSR [5] presents a pre desk study unexploded ordnance review. It concludes that a detailed assessment of UXO is not essential.

4 Field and laboratory studies

4.1 Geomorphological/geological mapping

4.1.1 The findings of the geomorphological and geological mapping undertaken during PCF Stage 3 are presented in Appendices A and B respectively.

4.2 Ground investigation

4.2.1 Ground investigation to support the preliminary design has been conducted in two phases and termed Phase 1 and Phase 2. The Phase 2 ground investigation scope was split into two, namely: Phase 2A to support the preliminary design (the findings of which are reported as part of this GIR); and Phase 2B to support detailed design. The scope of the detailed design ground investigation is defined in the Annex A Addendum [4].

4.2.2 The Phase 2A ground investigation considered in this GIR was undertaken between March 2019 to December 2020 by Geotechnical Engineering Limited (GEL). The scope of the Phase 2A ground investigation was developed during PCF Stage 2 and was amended during PCF Stage 3. Geotechnical Engineering Limited were commissioned by Osborne on behalf of Highways England to carry out the Phase 2A ground investigation.

4.3 Description of fieldwork

4.3.1 The scope of the Phase 1 ground investigation was as follows.

Table 4-1 Scope of Phase 1 ground investigation

Fieldwork component	Description
Exploratory holes	Five dynamic sampling with rotary core and/or rotary open hole follow on boreholes to depths ranging between 36 and 100m below ground level
	Three open hole rotary boreholes
In-situ testing	SPT testing was undertaken in boreholes in the superficial deposits
Installations	Standpipe installations with data loggers installed in all boreholes

Note: bgl = below ground level

4.3.2 The factual information is presented in the Phase 1 factual report dated April 2019 [2].

4.3.3 The exploratory locations from the historical ground investigations and the Phase 1 ground investigation are shown on the Exploratory Hole Location Plans (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000001 to -000006) in Appendix J.

4.3.4 The Phase 2A ground investigation is ongoing at the time of writing. This report is based on data collected up to December 2020. The scope of intrusive investigations undertaken in Phase 2A summarised in Table 4-2.

Table 4-2 Scope of Phase 2A ground investigation

Fieldwork component	Description
Exploratory holes	46 No. dynamic sampling with rotary core follow on with depths ranging between 4m bgl and 105m bgl

Fieldwork component	Description
	19 No. rotary core boreholes with depths ranging between 15 and 100m bgl
	Two cable percussive holes up to 16.8m bgl
	Eight inclined (45°) rotary core boreholes with depths ranging between 22m and 49m from the top of the hole
	26 No. trial pits with depths ranging between 0.75 and 3.6m bgl
	Four observation pits with depths of between 4 and 5m bgl
	Six Cone Penetration Tests (piezocone) (CPTu) up to 15m bgl
In-situ testing	SPT testing was undertaken in boreholes, in the superficial deposits and in the bedrock of the Lias Group
	Hand shear vane tests on cohesive material in the side of inspections pits or on excavated material from trial pits or dynamic samples
	Hand shear vane tests on undisturbed samples from boreholes
	Seven variable head tests in standpipe installations using a combination of water displacement tests (slug tests) and addition/removal of water from the installations
Installations	Groundwater level monitoring within 45 No. boreholes comprising: • 50mm diameter slotted standpipe • Dual installation in two boreholes comprising a 50mm diameter slotted standpipe and second 19mm diameter slotted standpipe • Piezometers in two boreholes (CP215 and CP204) Installations have been monitored (dipped) weekly during the fieldwork and are to continue monthly until August 2021
	Groundwater data loggers within 14 No. of the standpipes. The groundwater level was monitored from completion of the installation until December 2020. Data was downloaded from the data loggers monthly and the standpipe was dipped for calibration. Monitoring is ongoing, but data collected after December 2020 will be included in the Final GIR.
	Inclinometers within seven boreholes and monitored at least monthly from installation until December 2020. Monitoring is ongoing, but data collected after December 2020 will be included in the Final GIR.

Note[1]: bgl = below ground level
Note[2]: 86% of Phase 2A exploratory holes had been completed at the time of writing (completed prior to December 2020)

4.3.5 Locations of the Phase 2A exploratory holes [3] (completed to 1 December 2020), the historical ground investigations and the Phase 1 ground investigation [2] relative to the Preliminary Design alignment are presented on drawings HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000001 to -000006 in Appendix J.

4.3.6 The Phase 2A ground investigation factual report including AGS digital data, prepared by Geotechnical Engineering Limited is available as a separate document [3] and as ES Appendix 9.1.

4.4 Results of in situ tests

4.4.1 The results of the in-situ tests listed in Section 4.3 are presented in the ground investigation factual reports [2] [3]. A discussion of the results is presented in Section 5 of this report.

4.5 Geophysical surveys

4.5.1 Downhole geophysical testing was carried out by European Geophysical Services Limited (EGS) in 31 boreholes (six in Phase 1 and 25 in Phase 2) and by Robertson Geoservices in one borehole. The downhole geophysical testing including all or several of the following tests:

- optical images
- acoustic images
- temperature and conductivity
- impellor flowmeter
- resistivity
- 3-armed calliper
- natural gamma and density (gamma-gamma)

4.5.2 Surface geophysics was carried out by TerraDat to characterise the superficial deposits, map the bedrock and identify structural geology features such as faults or mass movement features such as gulls. The surface geophysics comprised:

- 24 survey lines using Electrical Resistivity Tomography (ERT), P and S wave refraction and Multichannel Analysis of Surface Waves (MASW) along all survey lines
- Three areas surveyed using an electromagnetic (EM) ground conductivity survey

4.5.3 Two ERT/P and S wave refraction/MASW survey lines, and one area of EM ground conductivity mapping were still to be undertaken at the time of writing this GIR.

4.5.4 The ESG, Robertson Geoservices and TerraDat reports are included with the GEL factual report [3]. The interpretation of the surveys is presented in Section 5 of this GIR.

4.6 Other fieldwork

4.6.1 An archaeological investigation is being conducted across the site. The archaeological investigation comprises:

- A detailed gradiometer survey to identify magnetic anomalies in the superficial deposits. The investigation was carried out and interpreted by Wessex Archaeology Limited. The report is appended to ES Chapter 6 Cultural Heritage (Document Reference 6.2).
- Trial trenching of the near surface superficial deposits.

4.6.2 The findings of the investigations are reported on in detail in the Environmental Statement.

4.7 Laboratory testing

4.7.1 The following sections summarise the laboratory tests (both geotechnical and in relation to soil and water quality) carried out as part of the Phase 1 and Phase 2A ground investigation. Table 4-3 below provides a summary of the geotechnical laboratory testing undertaken.

Table 4-3 Scope of geotechnical laboratory testing

Material	Category	Geotechnical test type
Soil	Classification tests	Natural moisture content tests
		Atterberg Limits tests
		Particle Size Distribution (PSD) tests
	Strength testing	Unconsolidated Undrained (UU) triaxial compression tests
		Consolidated Undrained (CUT) triaxial compression tests with the measurement of pore water pressure
		Consolidated drained small shear box tests
		Ring shear tests
		Laboratory vane
	Consolidation tests	One dimensional consolidation tests
	Earthworks tests	Compaction tests (dry density/moisture content relationship testing)
		California Bearing Ratio (CBR) tests
		Moisture condition value tests
	Chemical tests	pH, water soluble Sulfate, acid soluble Sulfate and Total Sulphur testing on soil and groundwater samples – BRE SD1 (2005) suite
		Organic matter content tests
		Carbonate content
Rock		Point Load Index (PLI) tests
		Uniaxial Compressive Strength (UCS) tests
		Natural moisture content
		Indirect tensile strength by Brazilian testing
		Los Angeles coefficient
		Slake durability
		Shear box test on fracture
		Thin section analysis

4.7.2 Soil samples were obtained from made ground and natural ground encountered across the scheme area. Some of which were subject to dry weight and leachate soil analyses. The results of which are presented in Appendix H.

4.7.3 Groundwater samples were obtained from groundwater monitoring installations located along the scheme and subject to a suite of chemical tests. A summary of the results is shown in Appendix H.

5 Ground summary

5.1 Landscape and topography

5.1.1 Table 5-1 below includes a brief overview of the landscape, elevation and main geographical features that surround the scheme.

Table 5-1 Summary of scheme landscape and topography

Chainage	Landscape and topographical review
Ch 0+000 to Ch 1+700	The alignment follows the tributary of Norman's Brook up Crickley Hill, rising from ~95m AOD to ~210mOD. The tributary of Norman's Brook is topographical low in this part of the scheme, with slopes rising to the north and south up to the Cotswold escarpment. The topography and features associated with this part of the scheme are discussed in more detail in Appendix A and summarised in Section 5.3.
Ch 1+700 to Ch 3+070	The ground level rises from ~210m AOD to ~280m AOD between Ch 1+700 and Ch 3+070. From Ch 1+700 to Ch 2+000 the alignment is located within an existing cut approximately 20m deep with side slopes of around 35°. At roughly Ch 2+000 the alignment stops following the north-east south-west trending valley/existing cut and climbs within cut to the southeast.
Ch 3+070 to Ch 3+450	Between Ch 3+070 and Ch3+160 the ground level falls approximately 20m as the alignment crosses the Churn Valley, before rising back to ~280m AOD by Ch 3+450. The axis of the Churn Valley slopes down to the east, which is almost perpendicular to the alignment. The topography and features associated with this part of the scheme are discussed in more detail in Appendix A and summarised in Section 5.3.
Ch 3+450 to Ch 5+500	Beyond Ch 3+450 the alignment roughly follows the existing ground level which gently falls to the south east (from 280 AOD to 260 AOD). There is some variation in the existing ground level resulting in minor fill and cutting of up to approximately 7m deep.
B4070	The B4070 roughly follows the existing topography, which steeply rises from Barrow Wake (~285 AOD) at the western end, peaks at 290 AOD at Ch 0+240, before gently sloping down to 275 AOD in an easterly direction. Cuttings of approximately 5m are proposed at the western and eastern ends.

5.1.2 A detailed (0.25m horizontal resolution) Digital Terrain Model (DTM) model derived from an airborne LiDAR survey [9] has been used to carry out terrain analysis to identify existing topographical features and inform the geomorphological mapping of the Crickley Hill and the Churn Valley slopes, as presented in Appendix A.

5.2 Geological interpretation

General

5.2.1 The following section describes the ground encountered as part of the intrusive and geophysical ground investigations carried out across the scheme.

5.2.2 The ground model across the scheme has been developed from the following:

- Site walkover observations, including field based geological and geomorphological mapping (refer to Appendices A and B)

- Desk based geomorphological mapping using the results of terrain analysis
- Historical and recent intrusive ground investigations
- Surface geophysics carried out as part of the Phase 2A ground investigation
- Detailed stratigraphical logging conducted on selected boreholes by the British Geological Survey (refer to Appendix C)
- Published information presented in the PSSR [5]

5.2.3 Any changes to the published information based on the findings of this GIR are presented below and annotated on drawings HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 in Appendix J. Selected cross and long sections are presented in Appendix E that present the current understanding of the ground model.

Strata encountered

5.2.4 The interpreted ground conditions encountered across the scheme based on the ground investigations are summarised in Table 5.2. Further details are presented in Sections 5.5 to 5.14. The information presented by the BGS on typical thicknesses (refer to Appendix C) has also been used to supplement the information in Table 5-2.

Table 5-2 Stratigraphic sequence and typical proven thickness'

Strata	Areas encountered	Proved thickness (m)
Topsoil	Encountered in most holes across the length of the scheme.	0.1-0.4
Made ground	Sporadically encountered between Ch 0+700 and Ch 1+700, Ch 1+850 and Ch 2+500 and Ch 5+000 to 5+860	Up to 2.6m
Alluvium	Not encountered as part of the Phase 1 and Phase 2A GI and any soft deposits have been considered as part of the mass movement deposits.	Not encountered
Cheltenham sand and gravel	Ch 0+000 to Ch 0+500 Encountered in the lower part of the Crickley Hill valley	1 to 2m thick
Mass movement deposits	Ch 0+500 to Ch 1+750 Below the scheme footprint and on the wider northern and southern slopes of the Crickley Hill Valley	0.7 to 22.5m thick
	Ch 3+100 On the side slopes of the Churn Valley.	1 to 3.7m
Head	Ch 1+750 to 5+500 Superficial material mobilised due to slope movement processes	
	Material overlying Inferior Oolite	0.2 to 2.5m thick (typically <1m)
	Material overlying Great Oolite Group - limestone	0.2 to 3.7m (typically <1m)
	Material overlying Fuller's Earth Formation	0.2 to 2.6m (typically 0.3 to 1.5m)
	Ch 2+950 to Ch 3+500	10 to 15m thick

Strata	Areas encountered	Proved thickness (m)
Great Oolite Group – limestone (includes White Limestone and Hampen Formations but not separated out in this GIR)	Encountered between the Shab Hill Fault and the Shab Hill Barn Fault – thickest towards the southwest	
	Ch 3+500 to Ch 5+500 Sporadically encountered from the south of Ch 3+500	1.5 to 4m thick
Great Oolite Group - Fuller's Earth Formation	Ch 2+900 to Ch 3+000 Encountered from ground surface prior to Shab Hill Fault	1.5m thick
	Ch 3+000 to Ch 3+500 Underlying the GOG limestone between the Shab Hill Fault and the Shab Hill Barn Fault	12m thick
	Ch 3+500 to Ch 4+750 Encountered between the Shab Hill Barn Fault and the Stockwell Fault and partially overlain by the GOG - limestone	5m to 20m thick (>25m where not penetrated)
	CH 4+750 to Ch 5+500 Encountered from ground surface south of the Stockwell Fault	13m thick (>18m where not penetrated)
Inferior Oolite Group	Present beneath the scheme from Ch 1+750 to Ch 5+500. Exposed at surface between Ch 1+750 and Ch 2+920. Beyond Ch 2+920 it underlies the Fuller's Earth Formation. (From Ch 2+050 to Ch 2+600 there is a gap in GI information – to be completed post issue of this GIR)	Formation thicknesses presented below:
	Salperton Limestone Formation	6.5m to 11.5m thick (average 9m)
	Aston Limestone Formation	0.5m to 5.2m thick (average 2m)
	Birdlip Limestone Formation	49m to 55m thick (average 52m)
Lias Group – Bridport Sand Formation	Proved to underlie the IOG from Ch 1+750 to Ch 2+500 and Ch 3+500 to Ch 5+500. To the south of the scheme not fully penetrated (more than 37m thick)	10m to 28m thick (average 19m)
Lias Group – mudstones (includes Whitby Mudstone Formation, Marlstone Rock Formation, Dyrham Formation, Charmouth Mudstone Formation)	Ch 0+000 to Ch 1+700 Encountered beneath the Cheltenham Sands and Gravels and the Crickley Hill mass movement deposits. Upper weathered surface 1.4m to 18m thick overlying mudstone Ch 1+700 to Ch 2+100 Proven below the Bridport Sand Formation (Note that the Marlstone Rock Formation is a thin (up to 1m thick) limestone band that has not been encountered consistently)	Not proven over both chainage extents [Lias group >350m [5]]

Updates to published solid and superficial geology

5.2.5 On the basis of the information listed in 5.2.2, the published geological map has been amended and is presented within HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 in Appendix J. The amendments are summarised below and more detail on the basis for changes and uncertainty is provided in Appendix B:

- The boundary between the Inferior Oolite Formation and the underlying Lias Group has been refined, especially within the vicinity of the existing A417 towards the top of the escarpment slope.
- An outcrop of Fuller's Earth Formation has been presented to the north-east side of the Shab Hill Fault.
- All geological boundaries within the Churn Valley-Shab Hill fault block have been refined. This includes the mapped extent of mass movement deposits on the north-western slope of Churn Valley.
- Within the Shab Hill Barn-Stockwell fault block all geological boundaries have been refined.
- The extent of Great Oolite Group limestone is not as extensive as originally mapped by the BGS. More Fuller's Earth Formation is at the surface from Ch 4+750 to Ch 5+500.
- An outcrop of Inferior Oolite has been presented within the base of Nettleton Bottom.
- The mapped extent of mass movement deposits within Nettleton Bottom has been refined.
- The thickness of Bridport Sand Formation is on average 20m thick but towards the south of the scheme thickness of greater than 37m can be found based on the borehole that didn't penetrate the formation. This is thicker than the 0 to 10m thickness reported in the PSSR [5]. The formation also appears to be more laterally extensive from the escarpment than anticipated in the PSSR [5].
- Presence of Marlstone Rock is not consistently identified across the scheme. This may suggest it was not present as a continuous stratum, or it could be due to disturbance resulting from the escarpment forming processes or is deeper than anticipated.

5.2.6 Commentary on the above findings is presented on the selected geological cross sections presented in Appendix E.

Updates to the published structural geology

5.2.7 The surface trace of local and regional faults that extend through the scheme have been confirmed and/or refined on the basis of information listed in Section 5.2.2. In addition, three new faults have been identified, including the following:

- Churn Valley Fault, which extends in a south-east to north-west orientation and downthrows to the south-west.
- Cally Hill Fault, which extends in a south-west to north-east orientation and downthrows to the south-east.
- Nettleton Bottom Fault, which extends in a north to south orientation and downthrows to the west.

5.2.8 The key lines of evidence that have been used to map the positions of faults and commentary on the level of uncertainty is provided in Appendix B:

5.3 Conceptual ground model

5.3.1 One of the key areas in terms of ground model is associated with the mass movement deposits along Crickley Hill. Figure 5-1 presents the conceptual geological block model for the Crickley Hill valley that has been based on the geomorphological mapping, geological interpretation and the numerous studies on slope processes within the Cotswolds [5].

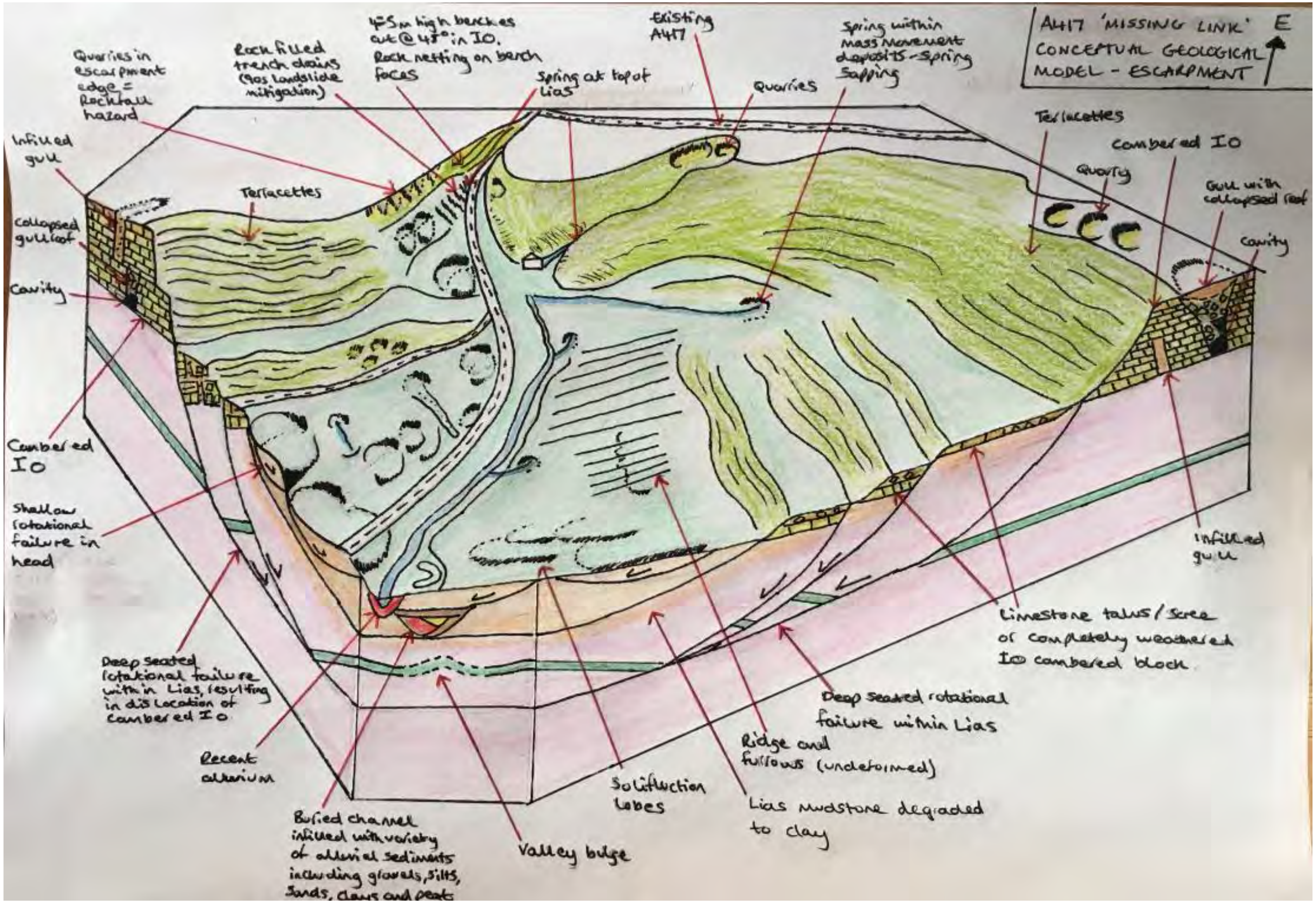

Figure 5-1 Conceptual geological block model – Crickley Hill

5.4 Ground conditions and material parameters - General

5.4.1 The ground conditions described in the following sub sections (5.5 to 5.19), have been deduced from the available site investigation data, that includes reference to both the Phase 1 and Phase 2A investigations and where considered necessary to supplement the site investigation data further reference is made to the previous factual and interpretative reports.

5.4.2 Within the following sub sections details of the stratigraphy along the route in general are described in addition to the engineering properties. Engineering properties are presented as ranges and average values. Characteristic values have not been derived in this report except in some instances where it was necessary to make sense of the data e.g. where standard penetration tests were subsequently used to derive parameters from empirical relationships and for assessments of aggressivity to buried concrete. More comprehensive consideration of characteristic parameters will be presented as part of the update to the GIR during the next stage of design. Parameter plots are presented in Appendix F. Details on the hydrogeological interpretation, aggressivity to concrete and geoenvironmental considerations for the scheme are also presented.

5.4.3 Rock mass characteristics have been considered from data obtained from core recovery, downhole geophysics and from fieldwork. The term "discontinuity" has been used as a geological descriptor that incorporates bedding and joints but the term "fractures" is used when reporting the fracture spacing characteristics from the engineering logs. As such, the term fracture spacing is equivalent to the term discontinuity (bedding and joints) as presented in the geological descriptions on rock mass quality.

5.5 Topsoil

General

5.5.1 Topsoil was encountered over most of the scheme from ground surface to typical depths of around 0.1 to 0.4m with an average depth of 0.2m below ground level.

Description

5.5.2 The topsoil was typically encountered as a dark brown grey gravelly silt/clay with frequent rootlets. The topsoil was occasionally described as soft ranging to stiff.

Engineering properties

5.5.3 A limited scope of laboratory testing has been conducted on the topsoil generally in and around the Shab Hill junction area of the scheme (refer to Appendix F, figures F1.01 to F1.05). The following summarises the testing:

- Five natural moisture content tests ranging from 20 to 62%.
- Six Atterberg Limits tests with plasticity index ranging from 15 to 63 with material behaviour ranging from high to very high plasticity clay and silt.
- One particle size distribution test confirming the typical logged description as a slightly sandy, slightly gravelly clayey silt.
- Twenty four hand vanes on in-situ material from depths up to 0.2m that recorded undrained shear strengths (peak) ranging from 17 to 100kN/m^2 with an average of 50kN/m^2. This range corresponds with the logged consistency range.

5.6 Made ground

General

5.6.1 Made ground was encountered in sixty-six of the historical, Phase 1 and Phase 2A exploratory holes. Made ground was predominantly encountered along Crickley Hill from Ch 0+700 to Ch 1+700, from Ch 1+850 to Ch 2+500, towards the end of the scheme from Ch 5+000 to 5+860 and sporadically along the existing A417 south of Air Balloon roundabout to Parson's Pitch. Reference should be made to Figure 9.7 from the Environmental Statement Geology and Soils chapter (drawing HE551505-ARP-EGT-X_XX_XXXX_X-DR-LE-000015).

5.6.2 Along Crickley Hill, made ground occurs sporadically from Ch 0+700 (associated with the Fly Up property) to Ch 1+350 and is then encountered in several exploratory holes from Ch 1+400 to Ch 1+700 associated with Grove Farm.

Description

5.6.3 The typical descriptions of the made ground are presented in Table 5-3 and have been split geographically along the scheme as follows.

- Ch 0 to Ch 0+700
- Ch 0+700 to Ch 2+500
- Ch 2+500 to Ch 5+860

5.6.4 From Ch 0+700 to Ch 2+500, 12 of the Phase 2A borehole logs suggest made ground but there is no clear evidence to suggest the material is made ground (e.g. no anthropogenic inclusions or other reasons to suggest made ground). This typically includes lithological descriptions that appear to be similar to topsoil. These have been omitted from Table 5-3.

Table 5-3 Typical descriptions of made ground

Scheme location	Typical description	Thickness (m)
Ch 0+000 to Ch 0+700	Encountered in five exploratory hole locations adjacent or within the existing Fly Up Bike Park development. Typically, dark brown, red, yellow and grey clayey sandy red fine to coarse red and yellow brick, tile, clinker, concrete. Made ground interpreted to be associated with the existing land use and not considered likely to be encountered consistently across the scheme footprint.	0.3 to 1.1
Ch 0+700 to Ch 2+500	Variable and heterogenous over this extent. Identified in discrete/localised areas based on areas of historical and current land use:	
	Existing road surfaces Made ground containing a top layer of tarmacadam is present in boreholes drilled in existing road surfaces, including boreholes DSRC110 and DSRC418.	0.2
	Grove Farm Variable, with both cohesive and granular varieties and containing frequent amounts of charcoal fragments as well as subordinate amounts of slag, clinker, and concrete (CP105, CP106 and TP207)	2.6

Scheme location	Typical description	Thickness (m)
	Olfactory evidence of hydrocarbon contamination has been identified in CP106 between 0.4 and 0.75mbgl, with a hydrocarbon odour noted within dark grey gravel of mixed lithologies (including slag).	
	North of Grove Farm (and north of the proposed alignment) Less extensive areas of made ground, predominantly cohesive with fewer anthropogenic inclusions including ceramic, brick, and glass. Made ground likely to be associated with a series of farm buildings where boreholes CP213 and CP215 were advanced.	0.9
	North east of Grove Farm and to the west of Emma's Grove A cluster of borehole locations have identified made ground along the southern perimeter of the proposed alignment at the location of the Grove Farm Underpass (DSRC107, DSRC108, DSRC110, RC507, RC508 and RC509). The made ground heterogenous, comprised of either silt, sand, clay and gravel-with inclusions of bituminous materials, clinker, concrete, and brick.	1.25
Ch 0+700 to Ch 2+500	Made ground has been identified in five boreholes from the Phase 2A investigation, as well as eight boreholes from historical investigations. No clear evidence on why material classified as made ground - the logs do not indicate the presence of any anthropogenic materials in the materials and there is no further information to suggest that these materials are made ground.	-

5.6.5 Reference is made to the potentially contaminative properties of the made ground encountered along the proposed scheme. In relation to the made ground encountered from Ch 0+700 to Ch 2+500, specific reference is made to CP106, DSRC419, OH405, DSRC415 and CP215 in the geo-environmental assessments (refer to Section 5.19 and Appendix H).

Engineering properties

5.6.6 A limited scope of laboratory testing has been conducted on the made ground (refer to Appendix F, figures F2.01 to F2.04) and the following summarises the testing:

- Moisture content testing conducted from exploratory holes along Crickley Hill (predominantly approaching or at Grove Farm and exploratory holes to the southern end of the scheme). Natural moisture content ranged from:
  - 3 to 26% with an average of 17% along Crickley Hill (out of the 15 tests four comprised granular material).
  - 2 to 27% with an average of 12% based on nine samples to the southern extent of the scheme.
- Atterberg Limits tests with the following ranges:
  - plasticity index ranging from 13 to 23% with an average of 18% based on eight tests along Crickley Hill. Material behaviour predominantly an intermediate plasticity clay.
  - plasticity index ranging from 17 to 30% with an average of 24% based on five tests towards the southern extent of the scheme. Material behaviour predominantly an intermediate plasticity clay.

- Fourteen particle size distribution tests were conducted on samples of made ground. The grading curves suggest a variety of cohesive and granular materials from slightly sandy clayey silt to slightly clayey sandy gravels.
- Standard penetration tests (SPT) recorded SPT N values ranging from N 4 to N65. One borehole (2009_BH01) has recorded consistently hight SPT N values whilst the remaining test results range from N 4 to N 15 with depth.
- A hand vane test at 0.2m depth from DSRC326 recorded an undrained shear strength of 31kN/m^2 and corresponds with the soft to firm logged consistency.

5.6.7 Based on the above, there is limited information and test data to derive geotechnical parameters for the made ground. In addition, based on the logged descriptions, the made ground is likely to be heterogeneous in nature and therefore its engineering properties will vary. Should there be a need to attribute engineering parameters to the Made Ground during design, this should be approached on a case by case basis for the specific areas under consideration.

5.7 Alluvium

5.7.1 Alluvium was not identified as part of the Phase 1 and Phase 2A ground investigations. Any soft deposits which may be associated with alluvium have been considered in Section 5.9.

5.7.2 Localised areas of alluvium are anticipated in the immediate vicinity of the tributary of Norman's Brook which may need to be excavated and replaced should these coincide with structure locations or in sub formations for earthworks.

5.8 Cheltenham sand and gravel

General

5.8.1 The Cheltenham Sand and Gravel (CSG) is anticipated to underlie the scheme from Ch 0+000 to Ch 0+500. No Phase 1 or Phase 2A ground investigations have been carried out over this extent (but ground investigation is proposed as defined in the Annex A Addendum [4]). As such, data from the historical A417 Brockworth Bypass GIR [13] (shown as GI series "1990b" on the exploratory hole plans) has been used within this section of the GIR to describe the CSG and present geotechnical parameters and engineering interpretations. Historically the CSG has been logged as "fan gravel" but is termed CSG in this report.

5.8.2 The historical exploratory hole logs used to inform this section are presented on the exploratory hole plans (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000001 to -000006) in Appendix J.

5.8.3 The scheme would be impacted by the CSG in the form of embankments founding on the CSG, cuttings within the CSG, material reuse from the CSG and pavement founded in the CSG.

Description

5.8.4 The CSG was generally encountered beneath topsoil, typically between 0.1 to 0.3m bgl, with thickness varying from 1 to 2m but logged up to 5.9m (borehole 1990b_B53).

5.8.5 Over the scheme extent, the CSG is typically encountered as stiff to very stiff brown mottled orange/yellow brown slightly sandy silty clay, with a little gravel becoming much sub-angular to sub-rounded fine to coarse gravel (and occasional cobbles) of predominantly oolitic limestone. Minor components of ironstone and calcareous siltstone gravel were also recorded.

5.8.6 Within three of the historical trial pits potential slip material has been identified below the CSG at 1.1 to 1.7m depth, 0.3 to 0.45m thick. The material is described as firm to very stiff grey brown clay with little to some limestone gravel. For this GIR this material has been interpreted to be part of the CSG but there is potential that is could represent solifluction of the upper Lias surface prior to deposition of the CSG. As part of the further ground investigation this assumption would need to be verified as one of the trial pits logged “some slickensiding”.

5.8.7 Near the base of the stratum, a likely transition zone into the underlying Charmouth Mudstone Formation of the Lias Group has also been noted. This is marked by a change to a blue grey/green grey colour over this zone.

5.8.8 Granular components of the CSG comprising predominantly gravel and cobbles of limestone were encountered from 0.5 to 1m below ground level in two exploratory holes (1990b_B53 and 1990b_T69). These holes are located beyond the start of the scheme and are not considered to be representative of the CSG anticipated to underlie the scheme.

Engineering properties

5.8.9 The historical test data has been discussed in the sections below and parameter plots from the historical GIR [13] are presented in Appendix F. Geotechnical laboratory test result plots included within the Brockworth Bypass GIR did not differentiate between granular and cohesive components of the CSG. Engineering judgement has been adopted during interpretation of the historical data that will need to be verified. Additional recommended ground investigation has been defined in the Annex A Addendum [4].

Classification

5.8.10 Classification testing conducted on the CSG is presented is summarised below (refer to Appendix F, figures F3.01 to F3.04):

- Moisture content range of 9 to 29% with an average of approximately 22%
- Plastic limit ranges from 12 to 27% with an average of approximately 21%
- Liquid limit ranges from 25 to 62% with an average of approximately 50%
- Plasticity Index varies from 11 to 35% with an average of 25%. Material behaviour ranges from low to high plasticity with a higher proportion of the data set recorded as intermediate to high plasticity.

5.8.11 Bulk density tests on the CSG generally varied between 19 to 21kN/m^3 (refer to Appendix F, figures F3.05 and F3.06).

5.8.12 Particle size distribution (PSD) test results (refer to Appendix F, figure F3.07) indicate the stratum to be highly variable ranging from well graded slightly sandy silty clays to slightly silty sands. Samples which comprise more than 35% fines content (i.e. percentage of materials passing 63μm) are considered to be representative of the anticipated CSG, indicating a well graded slightly sandy silty clay. This agrees with the typical engineering log description.

Strength parameters

Standard Penetration Tests

5.8.13 The results of standard penetration tests within the CSG are summarised below (refer to Appendix F, figure F3.08).

- SPT N ranges from 6 to 44. Within which two clusters of data area apparent, namely a cluster of SPT N values from 6 to 15 from 0.5m to 3m bgl and a second cluster of SPT N values greater than N 20.
- it is anticipated that the cohesive CSG are likely to be represented by the lower cluster of N values whilst the higher values represent the granular components.
- An average SPT N of 9 is considered representative of the CSG.

Undrained strength

5.8.14 No laboratory testing to determine undrained shear strength on the CSG was undertaken as part of the historical ground investigation.

5.8.15 Correlation of c_u with SPT N [14] indicates a c_u range of 30 to 75 kN/m^2 and an average of 45kN/m^2 based on the SPT N range of N 6 to N 15, average N of 9 and an f_1 coefficient of 5 based on a PI of 25%. The predicted range in c_u reflects the logged consistency of the material.

Drained shear strength

5.8.16 One shear box test was conducted on an undisturbed CSG sample from trial pit 1990b_T79 at 0.9m depth (refer to Appendix F, figure F3.09 and F3.10). Testing was carried out at normal stresses ranging from 25 to 100 kN/m^2 and up to displacements of 27mm. Classification testing conducted at the shear box test depth indicates a moisture content of 29% and a plasticity index of 11%. Based on the single test the following strength parameters are interpreted:

- $\phi'_{peak} = 32^o$, $c'_{peak} = 6$kN/m^2
- $\phi'_{residual} = 24^o$, $c'_{residual} = 0$ kN/m^2

5.8.17 Constant volume angle of shearing resistance (φ'_{cv}) can be determined for cohesive material using plasticity index values provided in BS8002:2015 [15]. This suggests a φ'_{cv} of 28° (and c' of 0kPa) based on an average plasticity index of 25%. The higher strength determined from the shear box is considered to be representative of the lower PI recorded when compared against the correlation in BS8002:2015 [15].

5.8.18 The residual strength can also be correlated against PI as presented by Lupini et al [16]. Based on an average plasticity index of 25% a residual shear strength in the order of 20 to 25^o could be anticipated. This agrees with the shear box testing.

Stiffness

5.8.19 Undrained and drained Young's Modulus (E_u and E') for the CSG has been based on the correlation for cohesive materials in CIRIA 143 [14].

- $E_u = 1.1 \times N_{60}$ (MPa)
- $E' = 0.9 \times N_{60}$ (MPa)

5.8.20 Based on the average SPT N of N 9, an average E_u of 10MN/m^2 and an average E' of 8MN/m^2 would be anticipated for the CSG.

Compaction

5.8.21 Seven dry density versus moisture content relationship tests ("heavy compaction") were undertaken on the CSG as part of the historical ground investigation (refer to Appendix F, figure F3.11). Optimum Moisture Contents (OMC) of 9% to 11% were recorded and corresponding maximum dry densities ranging from 1.78 to 2.02 Mg/m^3.

5.8.22 Two CBR tests recorded values of 17 and 34% recorded moisture contents of 20% and 9% respectively. The tests are not considered representative of the material and testing as defined in the Annex A Addendum [4] would be required as part of the next stage of design.

5.9 Mass movement deposits

General

5.9.1 Mass movement deposits (MMD) have been encountered in 117 exploratory holes across the scheme. The location of the MMD are presented in plan on drawings HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 and in section on the geological long sections (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010) in Appendix J. Based on the ground investigation the MMD have been encountered in two locations.

- Ch 0+500 to Ch 1+750 termed Crickley Hill MMD – encountered in 109 exploratory holes within the scheme footprint and within the wider slopes of the Crickley Hill valley.
- Ch 3+000 Shab Hill MMD – encountered in eight exploratory holes within the Churn Valley.

5.9.2 This section presents the findings of the ground investigations for the MMD and relevant design parameters. Cross sections illustrating the main findings of the ground investigations are presented in Appendix E (conceptual section A to D). For the purpose of this section, material that has undergone movement during current climatic conditions has been considered as MMD.

5.9.3 The scheme would be impacted by the MMD in the form of embankments founding on the MMD. Cut associated with the relocated tributary of Norman's Brook and the northern access to the Grove Farm Underpass would be required in the MMD. Commentary on hazards and risks from the MMD to the scheme (specifically for the Crickley Hill MMD) is presented in Section 7.4 of this GIR.

Description – Crickley Hill MMD

5.9.4 The typical descriptions associated with the Crickley Hill MMD are presented in Table 5-4. A further distinction between MMD located below the proposed earthworks footprint and the MMD encountered beyond the footprint on the northern and southern valley slopes away from the scheme is presented in Table 5-4.

Table 5-4 Typical descriptions of the Mass movement deposits (Crickley Hill Ch 0+500 to 1+700)

Typical description	Depth to upper surface (mbgl or mAOD)	Thickness (m)
Earthworks footprint Predominantly cohesive material with variable consistency encountered as:	Below topsoil or at ground level	0.7 to 22.5m
• Very soft to soft orange brown to green grey silty clay. Noted to be slightly sandy to sandy, slightly gravelly to gravelly, with gravel of limestone. (Soft clay either near surface or as layers within the slip mass. Where GI present within the earthwork's footprint, soft material anticipated to occur from Ch 0+800 to Ch 1+100 and Ch 1+250 to Ch 1+600. Material not consistently encountered in all exploratory holes across the earthworks footprint over these chainage extents).	(0 to 5m bgl)	(0.2 to 8.5m)
• Firm to stiff brown, orange brown, or grey to dark grey, slightly sandy clay. Noted as slightly gravelly to gravelly with gravel of limestone in several boreholes. Occasionally logged as soft to firm.	(0.1 to 5m bgl)	(0.5 to 5.5m)
• Stiff to very stiff dark grey mottled brown slightly sandy slightly gravelly clay with gravel of limestone. Generally encountered towards the base of the MMD.	(1 to 11.5m bgl)	(0.5 to 8.4m)
Granular material encountered within the cohesive MMD as layers and typically described as: • Medium dense to dense, occasionally loose, brown to yellow brown clayey sandy subangular to subrounded gravel of limestone. • Yellow brown slightly clayey gravelly sand with gravel of limestone. • Medium strong to very strong light grey limestone (logged as limestone or as cobbles and boulders of limestone). (The cohesive material comprises approximately 85% of the MMD and the granular material 15%. Of the cohesive component, the firm to stiff cohesive material forms around 60%, the soft around 20% and the stiff around 20% of the cohesive MMD).	(varies)	(0.4 to 2.8m)
Northern valley slope Predominantly cohesive material with variable consistency encountered as:	Below topsoil or at ground level	4.5 to 17.8m
• Soft brown to orange brown and grey slightly sandy gravelly clay with gravel of limestone (generally encountered near surface in seven boreholes).	(0 to 3m bgl)	(0.2 to 1.6m)
• Firm to firm to stiff brown to orange brown and yellow brown slightly sandy to silty clay and occasionally slightly gravelly with gravel of limestone.	(0 to 5.5m bgl)	(0.3 to 5m)
• Stiff to very stiff brown to dark grey slightly sandy clay or silt.	(3 to 8m bgl)	(0.4 to 13m)

Typical description	Depth to upper surface (mbgl or mAOD)	Thickness (m)
Granular material within the cohesive MMD as layers and encountered as: • Loose to dense yellow brown either sandy subangular to subrounded gravel of limestone or gravelly sand. Rare limestone cobble or band noted. (The cohesive material forms in total around 85% of the MMD and the granular material 15%. Of the cohesive component, the firm to stiff cohesive material forms around 50%, the soft around 5% and the stiff around 45% of the cohesive variety of the MMD).	(varies)	(0.1 to 4m)
Southern valley slope Predominantly cohesive material with variable consistency encountered as:	Below topsoil or at ground level	3.3 to 23.6m
• Soft brown mottled grey slightly sandy slightly gravelly clay with gravel of limestone (generally encountered within 2m of ground surface in six boreholes).	(0.2 to 2m bgl)	(0.3 to 3m)
• Firm to firm to stiff brown to orange brown mottled yellow brown slightly sandy, slightly to gravelly clay with gravel of limestone.	(0.2 to 2.5m bgl)	(0.4 to 4m)
• Stiff to very stiff orange brown to dark grey slightly sandy clay or silt.	(0.2 to 11m bgl)	(0.4 to 16m)
Granular material within the cohesive MMD as layers and encountered as: • Loose to dense yellow brown sandy subangular to subrounded gravel of limestone. Occasionally encountered as gravelly sand. (The cohesive material forms in total around 80% of the MMD and the granular material 20%. Of the cohesive component, the stiff to very stiff cohesive material forms around 70%, the soft around 10% and the firm around 20% of the cohesive variety of the MMD).	(varies)	(0.6 to 8m)

5.9.5 Five cone penetration tests (CPT) were conducted within the MMD on the southern valley slope. Based on the nearest boreholes three of the CPTs did not penetrate the full thickness of the MMD. In general, the CPTs:

- picked up the variability between the granular and cohesive MMDs.
- Where the MMD were penetrated by the CPTs (based on the nearest boreholes) differentiation between the slip mass and the underlying Lias Group could be observed as a continuous rise in sleeve and cone friction below the predicted base of the slip mass (CPT202 and CPT204).

5.9.6 The Crickley Hill MMD are variable in composition but are predominantly cohesive. The granular material and relict limestone blocks are interpreted to have been originally part of the escarpment. The cohesive material is likely to have been part of the Bridport Sand Formation or Whitby Mudstone Formation of the Lias Group. At depth the distinction between the MMD and the Lias Group is not definitive. The following data has been used to assess the thickness of the

MMD identified in the logs noting that the data is relevant to the northern and southern valley slopes:

- Down hole geophysics
- Surface geophysics
- Inclinometer data

5.9.7 Down hole geophysics was conducted in six boreholes (five within the southern slope and one in the northern slope). In general casing was used that covered either all or part of the MMD. Where casing covered part of the MMD, the following is noted for the downhole geophysics within the non-cased MMD:

- Large peaks in calliper readings at varying depths that can be related to logged features such as core loss (CP208), a 20^{o} discontinuity (DSR207) and logged fissures (DSRC224).
- Other features such as natural gamma, short and long spaced density were generally constant below casing level with minor peaks.

5.9.8 Interpretated features within the surface geophysics are presented in Appendix C of this GIR. Some of the main features identified within the surface geophysics are summarised below:

- Granular component identified as strongly resistive layers on the EM and ERT surveys. Occurs as zones within the cohesive (less resistive) material generally 5m deep and 5 to 50m in length towards the surface (refer to conceptual cross sections in Appendix E). Potential for increased granular material towards the upper reaches of the slopes and up chainage along the scheme as the Crickley Hill valley narrows.
- Conductive (potentially moisture rich zones) identified:
  - towards the base of the southern valley slope. This may correspond to the soft clays logged in the boreholes.
  - within the MMD generally towards the mid-section of the southern slopes.
- The MASW picks up the MMDs with a reduced stiffness compared to the underlying Lias Group. The S wave velocities within the MMD are <500m/s. Based on this the thickness of the MMD varies from around 10m to 25m. This broadly agrees with the thicknesses logged in the boreholes (refer to conceptual cross sections in Appendix E).

5.9.9 Seven inclinometers have been installed and monitored within the Crickley Hill valley slopes; three within the northern slopes and four within the southern slopes approximately between Ch 1+200 to 1+350. The following summarises the main findings (further assessment of the findings is presented in Section 7.4).

- Monitoring was conducted from June 2019 (southern slope inclinometers) and September 2019 (northern slope inclinometers) to November 2020 (all inclinometers).
- All inclinometers have recorded movement with resultant movements ranging from downhill to parallel with the slope profile.
- Recorded maximum resultant movements range from 4 to 6mm for the northern valley slope and 5.5 to 9.5mm for the southern valley slope predominantly from November 2019 onwards.
- Within the northern valley slope, two of the inclinometers (CP217 and CP214) recorded larger resultant movements (up to 5mm) within the top 9m of the inclinometer whilst the third (CP213) recorded larger resultant movements

within the top 1.5m (5mm) but possible movements down to around 15m (3mm) have been recorded in recent visits. Movements in CP217 and CP214 have been continuous since early 2020 whilst movements in CP213 have been sporadic. The movement depths at around 9m coincide with the base or within a metre of the base of the MMD logged in CP217 and CP214.

- Within the southern valley slope, varying depths of resultant movements were recorded. Within CP230 and CP209 resultant movements (up to 6mm) down to around 9m depth were recorded from November 2019 that became more consistent from around January 2020. Within these boreholes, the movement depths of 9m are roughly located within 2m of the inferred base of the MMD. Within CP208, resultant movements were generally small (generally less than 1mm) up until June 2020 after which resultant movements from 4 to 9mm were recorded to 20m depth. This depth is at the base of the logged MMD within CP208. DSRC207 recorded variable resultant movements that both increased and decreased during the monitoring period. Resultant movements of up to 8mm at depths to around 13m and 21m have been recorded over the entire monitoring period that are located within and close to the base of the MMD in DSRC207.

5.9.10 In general, the surface geophysics and the inclinometer data agree with the logged thicknesses of the MMD within the Crickley Hill area, with the latter indicating that movements at the base of the MMD are ongoing at recorded rates of between 4 and 6 mm per year. As part of the ground modelling, the logged borehole thicknesses in conjunction with the S-wave seismic velocities can be used to estimate the base of the MMD. There is only limited information available along the centre line of the scheme and the upper extent of the northern slopes.

Description – Shab Hill MMD

5.9.11 The typical descriptions associated with the Shab Hill MMD are presented in Table 5-5.

Table 5-5 Typical descriptions of the mass movement deposits (Shab Hill Ch 3+300)

Typical description	Depth to upper surface (mbgl or mAOD)	Thickness (m)
Predominantly, firm light red brown slightly sandy to slightly gravelly clay with gravel of fine to coarse limestone. Soft light brown slightly sandy slightly gravelly clay in TP210, TP603 and TP605 below the topsoil (0.5 to 2m thick) Weak limestone recovered as gravel and cobbles in DSRC310, DSRC311, DSRCOH412 towards the base of the MMD (0.7 to 3m thick) (this is likely to be weathered Salperton Limestone rather than slip mass)	Below topsoil or at ground level (247 to 257 mAOD)	1 to 3.7m

5.9.12 Surface geophysics lines 23 and 24 have extended across the Shab Hill valley. Line 23 is closest to the exploratory holes that have encountered MMD within the Shab Hill area. In terms of MMD, the survey line suggests the following:

- ERT23 indicates a conductive upper profile over the northern slope around 5m thick that agrees with the change in lithology above the limestone encountered in TP603 and DSRC311.
- The conductivity response over the southern slope is variable.
- The MASW23 section indicates a less stiff material over the northern slope that ties in with the conductive layer described above and with lower S-wave velocities (<300m/s) within the upper 3m.

5.9.13 The exploratory holes and the surface geophysics suggest that the MMD drape the side slopes of the Shab Hill valley and are locally thicker on the northern slope relative to the southern slope. There is a potential absence or thin veneer of MMD along the valley axis.

Engineering properties (Crickley Hill MMD)

Classification

5.9.14 Results of classification testing on samples of the MMD at Crickley Hill are presented below in Table 5-6. The associated plots are presented in Appendix F (refer to figures F4A.01 to F4A.04).

Table 5-6 Classification testing summary – MMD (Crickley Hill)

Property	Range	Average value	Observed trends
Bulk unit weight (kN/m^3)	18 to 21	19.5	General scatter around the range with depth. One low value of 15kN/m^3 at 2m depth in TP201 that may be related to possible organic matter logged in the TP.
Natural moisture content (%)	0.2 to 69	22	Natural moisture contents are higher within the upper 4m for the exploratory holes within the earthwork's footprint. Elevated natural moisture content results are not as pronounced for the near surface in the valley slopes. For all areas, natural moisture content becomes consistent with depth. The natural moisture contents are generally located below or slightly above the plastic limit except for the elevated moisture contents within the upper 4m that in some cases are close to the liquid limit. This ties in with the soft clay encountered over the earthwork's footprint extent.
Liquid Limit (%)	30 to 77	45	Plastic limit is generally consistent with depth with slight variations within the upper 8m for GI within the earthwork footprint. Liquid limit values show a greater scatter within the upper 8m with slightly less scatter recorded in the GI within the northern slopes. Below 8m depth there is less scatter, but values range from 35 to 55%. Based on the above, the plasticity index has a larger range in the upper 8m with less of a scatter range below this depth. However, the results from the northern and southern slopes do show some slightly larger variations in plasticity index with depth. Based on the Atterberg limit chart, MMD range from low to extremely high plasticity but the majority of the data intermediate to high plasticity with no distinction between the earthwork's footprint and the wider slopes.
Plastic Limit (%)	15 to 34	23	
Plasticity Index (%)	10 to 47	23	

5.9.15 Except for the higher moisture content and higher PI values within the near surface for the boreholes within the earthwork's footprint, the classification testing shows a similar trend in the data for the Crickley Hill MMD irrespective of location.

Particle size distribution

5.9.16 Particle size distributions for 40 samples are shown in Appendix F (figure F4A.05) for the Crickley Hill MMD. The testing indicates two broad material groups namely, slightly sandy silty clay and slightly clayey to clayey, slightly silty to silty sand or gravel. The grading curves reflect the cohesive and granular material descriptions from the exploratory holes.

Strength

Standard Penetration Tests

5.9.17 The results of standard penetration tests within the Crickley Hill MMD are presented in Appendix F (figure F4A.06).

5.9.18 The following summarises the findings of the SPT N_{60} results:

- SPT N_{60} range from 2 to 70 (ignoring 3 outliers) with an average value of N_{60} 25. In general, the N_{60} values range from N_{60} 5 to 20 down to 5m depth and then increase with depth. It is proposed that the following SPT N_{60} profile represents a lower bound to the data set:
  - <5m: N_{60} = 5
  - >5m: N_{60} = 5 + 3.5z (where z is the depth below 5m).
- SPT N_{60} values of less than N_{60} 5 are generally associated with the soft clay MMD logged within the upper surface of the boreholes. Three boreholes recorded SPT N_{60} values below N_{60} 6 within granular material.

5.9.19 The test results indicate a consistent increase in N values with depth between all holes.

Undrained strength

5.9.20 Unconsolidated undrained triaxial tests on 7 samples from the Crickley Hill MMD recorded undrained shear strength, c_u, values of 23 to 154 kN/m^2 (see Appendix F, figure F4A.07). This range corresponds with the logged soft to very stiff consistency of the material.

5.9.21 Ten consolidated undrained triaxial tests on samples from the Crickley Hill MMD were conducted. The values of c_u the consolidation stage confining pressure have been plotted in Appendix F (figure F4A.08). The recorded c_u values range from 38 to 327 kN/m^2 and increase with confining pressure.

5.9.22 Sixteen hand vanes conducted on material retrieved from boreholes CP206, CP215 and DSRC207 within the Crickley Hill MMD recorded peak c_u values of 35 to 103 kN/m^2 (refer to Appendix F, figures F4A.09 and F4A.10). There was no increase in c_u with depth, but the range corresponds with the logged firm to stiff consistency of the material within these logs.

5.9.23 Correlation of c_u with SPT N_{60} [14], based on the SPT N_{60} profile presented in 5.9.18 indicates a lower bound c_u range of 25 to 5m depth below which c_u increases to 200kN/m^2 at around 15m depth adopting an f_1 coefficient of 5 based on a PI of 23 (refer to Appendix F, figure F4A.11). The predicted increase in c_u with depth reflects the logged consistency of the material and the higher values are indicative of the very stiff material logged with depth.

5.9.24 Undrained shear strength can be predicted from the CPT cone resistance. The testing within the Crickley Hill MMD indicates c_u values of around 20kN/m^2 within the top 1 to 2m that increases to around 40 to 80kN/m^2 with depth (CPT202 and CPT203). Within CPT206, c_u values of less than 40kN/m^2 are predicted in the top 3m after which c_u increases with depth up to around 160kN/m^2. CPT204 and CPT205 predict c_u values of 80 to 150 kN/m^2 with depth. The CPT predictions are within the soft consistency range towards the top of the holes and within the firm to stiff consistency range with depth.

5.9.25 There is good agreement between the in-situ testing correlations with c_u and the laboratory derived c_u values. The composite plot of all c_u data presented in Appendix F (refer to figure F4A.12) should be used to develop the c_u profile for the Crickley Hill MMD as part of the final issue of this GIR.

Drained strength

5.9.26 Small reversed shear box tests were conducted on seven recompacted/remoulded samples and four undisturbed samples of the Crickley Hill MMD ranging in depths from 2 to 18.5m below ground level. A single historical shear box test from trial pit T81 [13] is included in the data set. The tests were conducted at normal stresses ranging from 25 to 600kN/m^2. The tests were conducted up to a displacement of 35mm and both a peak and residual angle of shearing resistance were reported. Classification testing conducted at the shear box test depths indicate moisture contents of 2 to 16% and plasticity indices of 10 to 33%.

5.9.27 The shear box test results are presented in Appendix F (refer to figure F4A.13, F4A.14 and F4A.15). The range in strength parameters based on the testing are as follows:

Table 5-7 Strength parameters for Crickley Hill MMD determined from shear box testing

Strength (based on shear box test)	Effective angle of shearing resistance range (ϕ') (degrees)	Effective cohesion range (c') (kN/m^2)
Peak	26 to 27	0 to 14
Residual	9.5 to 29	0

5.9.28 Five sets of three single stage (on 38mm diameter samples), one single stage (on a 100mm diameter sample) and two multi stage (on 100mm diameter samples) consolidated undrained with pore water measurement triaxial tests were conducted on undisturbed samples (UT100, core sub sample and a block sample) from the Crickley Hill MMD. The samples were obtained from depths ranging from obtained from 1.9 to 15.55m. Classification testing conducted at the triaxial test depths indicate moisture contents of 16.5 to 61% and plasticity indices of 10 to 39%.

5.9.29 The results of the triaxial testing are presented in Appendix F (refer to figure F4A.16). The testing suggests the following strength parameter range:

- effective angle of shearing resistance of 27 to 33°.
- effective cohesion (c') of 0 to 12kN/m^2 respectively.

5.9.30 The strength parameters from the consolidated undrained triaxial tests are broadly similar to the magnitude of ϕ'_{peak} and c'_{peak} interpreted from the shear box testing. The undisturbed shear box samples have recorded the cohesion component and agree with the triaxial testing. No cohesion is associated with the recompacted shear box samples.

5.9.31 Fourteen residual strength by ring shear tests were conducted on samples obtained from depths ranging from 2.5 to 13.9m. Classification testing conducted close to the ring shear test depths indicate moisture contents of 10 to 55% and plasticity indices of 13 to 39%.

5.9.32 The results of the ring shear testing are presented in Appendix F (refer to figure F4A.17). The testing suggests the following strength parameter range:

- residual effective angle of shearing resistance (ϕ'_r) of 9 to 24°.
- effective cohesion (c') of 0kN/m^2.

5.9.33 The strength parameters from the ring shear testing are in broad agreement with the residual strength parameter range determined in the shear box testing. Based on the Atterberg Limit testing near the sample depth of the shear box tests, the range in residual strength parameters can be associated with PI (refer to Appendix F, figure F4A.18). The higher samples that plot on the higher residual strength have recorded PI of less than 20% whilst the samples that plot on the lower residual strength line have recorded PI greater than 30%. Samples with PI in between these two, plot in between the strength parameter range.

5.9.34 To allow for a comparison of the laboratory based strength testing, constant volume angle of shearing resistance (φ'_{cv}) can be determined for cohesive material using plasticity index values provided in BS8002:2015 [15]. This suggests a φ'_{cv} of 28° (and c' of 0kPa) based on a plasticity index of 20% (based on the average PI from the effective stress and shear box test samples). This agrees with the interpretation presented on 5.6.30 and broadly with the shear box testing.

5.9.35 The residual strength parameter range presented can also be compared against PI as presented by Lupini et al [16]. Based on a plasticity index of 24% (average of the shear box testing) a residual effective angle of shearing resistance ϕ'_r in the order of 20° could be anticipated based on Lupini et al [16]. This is located in between the range in residual strength as is anticipated based on the relationship between PI and strength discussed in Section 5.6.34 which is towards the upper end of the range recorded by the testing.

5.9.36 A comparison of the strength data from exploratory holes from the northern slopes relative to those from the southern slope was made but there is no clear distinction in the data from either area. As such it is recommended that the strength data for the Crickley Hill MMD irrespective of area is adopted when drained strength is derived.

Stiffness

5.9.37 Stiffness parameters for the Crickley Hill MMD are presented due to the proposed embankments along Crickley Hill. Due to the larger proportion of cohesive material relative to granular, the stiffness parameters presented are based on correlations for cohesive materials.

5.9.38 Undrained and drained Young's Modulus (E_u and E') for the Crickley Hill MMD has been based on the correlation for cohesive materials presented in CIRIA 143 [14]:

- E_u = 1.1 x N_{60} (MPa)
- E' = 0.9 x N_{60} (MPa)

5.9.39 Based on the SPT N_{60} profile presented in 5.9.18, the following lower bound E_u and E' profiles would be anticipated for the Crickley Hill MMD:

- E_u = 6MPa to 5m depth, increasing to 45MPa at 15m depth
- E' = 4MPa to 5m depth, increasing to 35MPa at 15m depth

5.9.40 The CPT correlations suggest similar low stiffness values near surface but with depth the predicted stiffness is higher compared to the SPT correlation.

Consolidation

5.9.41 One oedometer consolidation test was carried on a sample of soft clay with pockets of organic material from TP201 at 1.9m depth. A pressure range of 25 to 400 kN/m^2 was applied that recorded values of the coefficient of volume compressibility (m_v) from 2m^2/MN to 0.35m^2/MN. The range generally corresponds to m_v values associated with high to medium compressibility soils [17]. This would only be applicable to the upper soft material rather than the Crickley MMD as a whole.

Compaction

5.9.42 Four dry density versus moisture content relationship tests were undertaken using a 4.5kg hammer. Sample depths ranged from 2 to 5m. Optimum Moisture Contents (OMC) of 11% to 12% were recorded and corresponding maximum dry densities ranging from 1.88 to 1.97 Mg/m^3. Natural moisture contents ranged from 19 to 25%.

Engineering properties (Shab Hill MMD)

Classification

5.9.43 Classification testing conducted on the Shab Hill MMD is presented in Appendix F (figures F4B.01 and F4B.02) and is summarised below:

Table 5-8 Classification testing summary – Shab Hill MMD

Property	Range	Average value	Observed trends
Bulk unit weight (kN/m^3)	NA	NA	No results.
Natural moisture content (%)	11 - 51	21	Spread of data with depth shows no trend Note, average and range ignores an elevated moisture content of 51%
Liquid Limit (%)	27 - 87	58	There is a slight variation in plastic limit with depth.

Property	Range	Average value	Observed trends
Plastic Limit (%)	19 - 35	26	Material behaviour ranges from low to very high plasticity with a higher proportion of the data set recorded as very high plasticity (this is reflected in the average PI).
Plasticity Index (%)	11 - 52	42	

Particle Size Distribution

5.9.44 Nine particle size distribution tests have been conducted on samples of Shab Hill MMD (Appendix F, figure F4B.03) that have recorded a range of material types. The gradings are predominantly cohesive and are in general agreement with the logged descriptions.

Strength

SPTs

5.9.45 Ten SPT N values have been recorded within the Shab Hill MMD (refer to Appendix F, figure F4B.04). Four tests conducted within cohesive MMD recorded N values from 9 to 29 with an average N 15. Four tests were conducted in granular MMD within borehole DSRCOH412 that recoded N values ranging from 19 to 43 with an average of N 32. Two tests were recorded within limestone in the MMD that recorded N values of 64 and 77.

Undrained strength

5.9.46 No laboratory testing to determine undrained shear strength (c_u) was conducted on the Shab Hill MMD.

5.9.47 Three hand vanes conducted on material retrieved from trial pits TP210, TP211 and TP603 within the Shab Hill MMD recorded average peak c_u values of 35 to 77 kN/m^2. The range corresponds with the logged soft to firm consistency of the material within these logs.

5.9.48 Correlation of c_u with SPT N [14] indicates a c_u range of 40 to 130 kN/m^2 based on the SPT N range of N 9 to N 29 and an f_1 coefficient of 4.5 based on a PI of 42% (refer to Appendix F, figure F4B.05). The predicted c_u reflects the logged consistency of the material.

Drained strength

5.9.49 One small reversed shear box test was conducted on a remoulded sample of the Shab Hill MMD from TP211 at 1.1m below ground level. The test was conducted at normal stresses ranging from 50 to 200kN/m^2 and conducted up to a displacement of 35mm. Classification testing conducted at the shear box test depth indicates a moisture content of 34% and a plasticity index of 47%. Based on the single test (refer to Appendix F, figure F4B.06 and F4B.07) the following strength parameters have been interpreted:

- $\phi'_{peak} = 25^o$, $c'_{peak} = 8$kN/m^2
- $\phi'_{residual} = 21^o$, $c'_{residual} = 0$ kN/m^2

5.9.50 A set of three (all 38mm diameter) single stage consolidated undrained with pore water measurement triaxial tests were conducted from the Shab Hill MMD.. The samples were obtained from a block sample from TP211 at 1.1m depth.

Classification testing conducted at the triaxial test depth indicates a moisture content of 34% and a plasticity index of 47%. The testing (refer to Appendix F, figure F4B.08) suggests the following strength parameters:

- effective angle of shearing resistance of 20°
- effective cohesion (c') of 25kN/m^2

5.9.51 To allow for a comparison of the laboratory based strength testing, constant volume angle of shearing resistance (φ'_{cv}) can be determined for cohesive material using plasticity index values provided in BS8002:2015 [15]. This suggests a φ'_{cv} of 24° (and c' of 0kPa) based on a plasticity index of 47%. Based on this it is likely that the shear box testing may represent the drained strength of the Shab Hill MMD.

5.9.52 No ring shear testing has been conducted on the Shab Hill MMD. The residual strength can also be correlated against PI as presented by Lupini et al [16]. Based on a plasticity index of 47% a residual shear strength in the order of 10 to 12° could be anticipated. This is much lower than the value predicted from the shear box testing.

Stiffness

5.9.53 Stiffness parameters for the Shab Hill MMD are presented due to the proposed embankments associated with the Shab Hill junction. The stiffness parameters presented are based on cohesive correlation.

5.9.54 Undrained and drained Young's Modulus (E_u and E') for the Shab Hill MMD has been based on the correlation for cohesive materials presented in CIRIA 143 [14].

- E_u = 1.1 x N_{60} (MPa)
- E' = 0.9 x N_{60} (MPa)

5.9.55 Based on the based on the SPT N range of N 9 to N 29, the following Eu and E' ranges would be anticipated:

- E_u = 10MPa to 30MPa
- E' = 8MPa to 26MPa

Consolidation

5.9.56 No oedometer testing to determine consolidation parameters was conducted on the Shab Hill MMD.

5.10 Head Deposits

General

5.10.1 The term head deposits has been used to describe the superficial material on the Cotswold escarpment from Ch 1+750 to Ch 5+500 where there is evidence that the superficial deposits have mobilised due to slope processes. If the bedrock has degraded without mobilising (i.e. it is not positioned on an existing slope or towards the base of a valley) it is considered weathered bedrock as opposed to head and is discussed within the rock sections. The head deposits have been divided into three, depending on the underlying bedrock geology namely: the Great Oolite Group limestone, the Fuller's Earth Formation or the Inferior Oolite Group.

5.10.2 The location of the bedrock geology is presented in plan on drawing HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 and the location of the encountered head deposits is shown on the geological long sections (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010) in Appendix J. Head deposits were encountered in 36 exploratory holes from Ch1+750 to 5+500.

5.10.3 The scheme would be impacted by the head deposits in the form of embankments founding on the head deposits, cuttings within the head deposits, material reuse from the head deposits and pavement founded in the head deposits.

Description

5.10.4 The typical descriptions, thicknesses and depth to bedrock are presented in Table 5-9.

Table 5-9 Typical descriptions of the head deposits

Head (parent strata)	Typical description	Thickness and depth to bedrock (m)
Head (Great Oolite Group Limestone)	Soft to firm brown sandy gravelly clay, often with a medium subangular limestone cobble content. Gravel is angular to subangular limestone.	0.2 – 2.5m Typically <1m
Head (Great Oolite Group Fuller's Earth)	Firm brown gravelly clay with medium limestone cobble content. Gravel is subangular fine to coarse limestone.	0.2 – 2.6m Typically 0.3 – 1.5m
Head (Inferior Oolite Group Limestone)	Soft to stiff brown gravelly sandy clay with medium limestone cobble content. Gravel is subrounded to subangular limestone.	0.2 – 3.7m Typically <1m

5.10.5 Areas that include thicknesses of head deposits towards the upper range of thickness in Table 5-9 are summarised below:

- Head deposits overlying the Great Oolite Group limestone is typically less than 1m. except for one hole (TP635) where it is 2.5m thick. The trial pit is in close proximity to the Shab Hill Fault.
- Head deposits overlying the Inferior Oolite Group limestone is typically less than 1m thick, but within three holes to the north of the existing A417 alignment near the Air Balloon roundabout (DS/RC319, DS/RC/OH304 and DS/RC325) it is 2.7 to 3.6m thick. These boreholes are close to the centre of Crickley Hill Valley with the land rising to the northwest and the southeast.

Engineering properties

Classification

5.10.6 Classification testing conducted on the head deposits is summarised below (refer to Appendix F, figures F5.01 to F5.03)

Table 5-10 Head deposits – Atterberg Limits and natural moisture content

Head (parent strata)	Assessment of results
Head (Great Oolite Group Limestone)	Eight natural moisture contents were recorded ranging from 14% to 53%, with an average of 24%. Seven Atterberg Limit tests were carried out. Plasticity index typically ranged between 33 and 50% and had one outlying result of 76%. Liquid limit ranges from 58 to 73%. The average plasticity index and liquid limit are 45% and 65% respectively which corresponds to a high plasticity clay.
Head (Great Oolite Group Fuller's Earth)	Six natural moisture contents were recorded ranging from 12% to 39%, with an average of 23%. Five Atterberg Limit tests were carried out. Plasticity index ranged between 23 and 49% with the data potentially occurring in two groups: plasticity index of 25% and 45%. Average liquid limit for the two groupings are 45% and 75%. Based on the Atterberg Limit chart material varies from an intermediate to very high plasticity clay.
Head (Inferior Oolite Group Limestone)	Eight natural moisture contents were recorded ranging from 8% to 18%, with an average of 13%. Eight Atterberg Limit tests were undertaken. Plasticity index ranged between 11 and 23% with an average of 17%. Liquid limit ranges from 28% to 39% which corresponds to a low to intermediate plasticity clay. Based on the Atterberg Limit chart material varies from a low to intermediate plasticity clay.

Table 5-11 Head deposits – particle size distribution test results

Head (parent strata)	Assessment of results
Head (Great Oolite Group Limestone)	Five particle size distribution tests were undertaken. The results varying between a material that predominantly comprises silt and clay particles to a material to predominantly comprises sand and gravel.
Head (Great Oolite Group Fuller's Earth)	Three particle size distribution tests were undertaken. Two samples are predominantly clay and silt, and one sample is predominantly gravel.
Head (Inferior Oolite Group Limestone)	Three particle size distribution tests were undertaken, and all are predominantly granular.

Bulk unit weight

5.10.7 There are no bulk unit weight results reported in the head deposits.

Standard Penetration Tests

5.10.8 Thirteen SPT N values have been recorded, one from head overlying the Fuller's Earth Formation, which has a value of N 47, twelve from head overlying the Inferior Oolite Group, with values ranging between N 3 and 61, but was typically between 10 and 25 (refer to Appendix F, figure F5.04).

Strength

Undrained strength

5.10.9 No laboratory testing has been conducted to determine undrained shear strength.

5.10.10 Hand shear vane tests, undertaken in head deposits from the Great Oolite Group limestone and Fuller's Earth Formation (refer to Appendix F, figures F5.05 and F5.06) recorded yielded peak shear strength values of between 26 and 91kN/m^2 (from 42 results) and residual shear strength values of between 10 and 42kN/m^2 (from 39 results), at depths of 0.1-2.6m bgl.

Drained strength

5.10.11 The head deposits overlying the Great Oolite Group (Fuller's Earth Formation and the limestone formations) comprise heterogenous material that is granular and cohesive whilst the head deposits overlying the Inferior Oolite Group are granular. No laboratory testing has been conducted to determine drained shear strength.

5.10.12 Using equation 7 from BS8002:2015 [15], the cohesive head deposits are interpreted to have a constant volume effective angle of shearing resistance (ϕ'_{cv}) range of 27^o to 24^o based on average plasticity indices of 25 and 45 respectively.

5.10.13 For the granular head deposits, ϕ'_{cv} can be estimated for granular soils from BS8002:2015 [15]. From a generalised description of the granular soils, comprising angular and subangular particles and being moderately to well graded, the corresponding critical angle of shearing resistance is 34°.

Stiffness

5.10.14 The drained Young's Modulus E' for the granular head deposits can be derived from the relationship between SPT 'N' values and E' (E'/N_{60} = 1.25MN/m^2) outlined by Stroud [14]. The SPT 'N' values typically ranged between 10 and 25, which corresponds to a stiffness of 12 to 30MN/m^2.

5.10.15 A single SPT has been conducted in the cohesive head deposits and it is not considered appropriate to develop stiffness parameters correlated from the single SPT N value.

Compaction

5.10.16 One compaction test has been undertaken on a sample of head deposits overlying the Great Oolite Group limestone. The sample was taken from TP635 at 1.5m bgl. Based on the laboratory and log description the sample is considered typical of the head deposits overlying the Great Oolite Group (slightly sandy, slightly gravelly clay).

5.10.17 The compaction test method used a 2.5kg dynamic compaction rammer and a CBR mould. An optimum moisture content (OMC) of 22% was reported with a maximum dry density of 1.58Mg/m^3. The initial moisture content was 32%.

5.10.18 A moisture condition value (MCV) to moisture content relationship test was undertaken on this sample. An MCV of 14 was reported at the OMC. No compaction tests were undertaken on samples of head deposits that overlay the Fuller's Earth Formation or the Inferior Oolite Group.

5.11 Great Oolite Group – (Hampen Limestone and White Limestone Formations)

General

5.11.1 The Hampen Limestone and White Limestone Formations of the Great Oolite Group have been combined in this report due to their similar engineering properties and are often referred to as the Great Oolite Group limestone (GOG limestone). They were encountered in 69 exploratory holes of which 14 exploratory holes are associated with the Phase 1 and Phase 2A ground investigations. The following section has been based primarily on the recent phases of ground investigation.

5.11.2 The location of the GOG limestone is presented in plan on drawing HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 and in section on the geological long sections (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010) in Appendix J. The following is a summary of the GOG limestone occurrence from the ground investigation.

- Ch 3+000 (refer to conceptual section F and G, Appendix E):
  - predominantly within the area of the proposed Shab Hill junction (Ch 3+000) between Shab Hill and Shall Hill Barn Faults (refer to). The GOG underlies head deposits and ranges in thicknesses of between 10 and 15m.
- Ch 3+500 to 5+500 (refer to conceptual section H, Appendix E):
  - sporadically encountered south of the Shab Hill Barn Fault (Ch 3+500 to Ch 5+500) and ranged in thickness from 1.5 to 4m. The recorded extent of the GOG to the south of the Shab Hill Barn Fault was less than suggested on the BGS mapping.

5.11.3 The lack of GOG limestone identified in the boreholes could be attributed to the difficulty in distinguishing the boundary between the Hampen Formation and the underlying Fuller's Earth Formation. The boundary is a transitional boundary with both formations in part comprising limestones interbedded with marls or calcareous sandstones.

5.11.4 The absence of GOG limestone in the southern part of the scheme is supported by the results of the downhole geophysics. The downhole geophysics generally show much higher gamma and calliper readings in the Fuller's Earth Formation.

5.11.5 The conductivity surveys pick up strong contrasts between the limestone of the Great Oolite Group and the Fuller's Earth Formation (refer to surface geophysics Zone 4 [3]).

5.11.6 The scheme would be impacted by the GOG limestone in the form of cuttings within the GOG limestone, with materials to be re-used within the embankments, some of which would be founding on areas underlain by the GOG limestone (e.g. Shab Hill junction) . A number of highway structures would also have foundations supported within the GOG limestone.

Description

5.11.7 The GOG limestone has been typically described as light yellowish to greyish brown very weak to weak (occasionally medium strong) thinly bedded bioclastic and ooidal limestone, with rare interlaminations of orangish brown sandy silt/clay.

Rock mass quality

5.11.8 The rock mass characteristics are summarised below.

- Two principal discontinuity sets have been recorded in the core logging:
  - The predominant set has been generally described as sub-horizontal to 20° and is interpreted to be bedding.
  - The second (less common) set is described as 50 to 70° (up to sub-vertical), assumed to be joints.
  - Both sets are generally recorded to be very closely to closely (occasionally medium) spaced undulating rough stained orangish brown rarely infilled (typically 1 to 5mm, up to 40mm) with orangish to yellowish brown clay.
  - The logged average fracture spacing typically ranged between 50 and 170mm, averaging 110mm (refer to Appendix F, figure F6.01).
- Discontinuities were recorded as part of the downhole geophysics surveys in two holes (DS/RC312 and OH411). The spacings typically ranged between 100 and 400mm and averaged 240mm. Bedding discontinuities commonly dipped in a south easterly direction at an angle of between 8° and 16°. To a lesser extent there were also discontinuities (assumed to be joints) that dipped in a north westerly, south westerly and rarely north easterly direction.
- Rock quality designation (RQD) values were generally between 0 to 20% for the first 2m, increasing to approximately 40 to 60% thereafter (refer to Appendix F, figure F6.02).

Engineering properties

Classification

5.11.9 Two moisture content tests have been undertaken on samples within the GOG limestone that recorded a natural moisture content of 1%.

5.11.10 No bulk density testing has been undertaken on samples of the GOG limestone.

Rock strength parameters

Standard Penetration Tests

5.11.11 Four standard penetration tests (SPT N) were conducted that recorded SPT N values of 60 to 230 with an average of 150 (refer to Appendix F, figure F6.03).

Point Load Index

5.11.12 Thirty two point load index tests ($Is_{(50)}$) have been undertaken recording $Is_{(50)}$ values ranging from 0.2 to 5.3MN/m^2 with an average of 1.8MN/m^2 (refer to Appendix F, figure F6.04). Ignoring outliers, $Is_{(50)}$ typically ranges from 1 to 3MN/m^2.

Unconfined compressive strength

5.11.13 No unconfined compressive strength (UCS) testing was conducted on the GOG limestone.

Rock mass strength

5.11.14 Insufficient data to derive rock mass parameters for the GOG limestone.

Rock mass stiffness

5.11.15 Insufficient data to derive rock mass stiffness for the GOG limestone.

Permeability

5.11.16 Limestones within the Great Oolite Group are considered the main water bearing formations where groundwater flows through fractures within the rock mass. Variable head testing was attempted at three locations, DSRC 218, DSRC 317 and DSRC 401, however due to the response zone not being fully saturated, a valid hydraulic conductivity value cannot be estimated. The results of the variable head tests are presented in the Phase 2A ground investigation factual report [3].

5.11.17 The results are discussed in further detail within the hydrogeological interpretation presented in Section 5.17.

5.12 Great Oolite Group – Fuller's Earth Formation

General

5.12.1 The Fuller's Earth Formation (FEF) lies stratigraphically between the overlying limestone of the Great Oolite Group and the underlying limestone of the Inferior Oolite Group (refer to Table 3-1 and the PSSR [5] for further details). The FEF is part of the Great Oolite Group but has been considered separately to the overlying limestones within this GIR.

5.12.2 The boundary between the FEF and the GOG limestones is a gradational boundary. Therefore, for the sake of the interpretation of the top of the FEF, this has been taken at the first downhole appearance of extremely weak and very weak mudstone or stiff clay and silt, interbedded with shelly limestone or calcareous sandstone.

5.12.3 The FEF was encountered in 88 exploratory holes of which 28 exploratory holes are associated with the Phase 1 and Phase 2A ground investigations. The following section has been based primarily on the recent phases of ground investigation. Selected relevant historical ground investigation [20] has also been considered.

5.12.4 The location of the FEF is presented in plan on drawing HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 and in section on the geological long sections (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010) in Appendix J. The following is a summary of the FEF occurrence from the ground investigation relative to existing ground level.

- Ch 2+900 to Ch 3+150 (refer to conceptual section G, Appendix E):
  - FEF is first encountered in RC516 at Ch 2+900 from surface to approximately 2mbgl (275mAOD).
  - The Shab Hill Fault has been identified on seismic survey lines 21 and 22 and is assumed to pass through the alignment at about Ch 2+950. The fault is downthrown to the south by an estimated 18m. To the south of the fault it is anticipated that there is thin sequence of the Hampen Limestone Formation overlying the FEF, which is anticipated to be between approximately 275mAOD and 258mAOD (4 and 21m bgl).

  - At approximately Ch 3+090 the Churn Valley cuts down through the FEF. The newly identified Churn Valley Fault lowers the level of the FEF to the south to between 248mAOD and 265mAOD (12m to 30m bgl).

- Ch 3+150 to Ch 5+500 (refer to conceptual sections G and H, Appendix E):
  - At Ch 3+510 the scheme crosses the Shab Hill Barn Fault, which has an anticipated throw of 20m to the north. On the southern side of the Fault the stratigraphy is approximately 20m higher. This exposes the FEF at surface, with its base at approximately 12m bgl (~270m AOD).
  - The base of the FEF deepens with increased chainage until the alignment crosses the Stockwell Fault at Ch 4+710. On the northern side of the fault, the FEF, which is approximately 25m thick, and is overlain by approximately 3m of Hampen Limestone Formation. On the southern side of the fault, the FEF is exposed at surface and is approximately 6m thick. The thickness of the FEF then increases once more with increasing chainage.
  - At Ch 5+500 it is anticipated to be some 25m thick.

- B4070 Ch 0+260 to 0+450 (refer to B4070 geological long section drawing):
  - The FEF is expected at ground level between approximate Ch 0+260 and Ch 0+450 of the B4070. It is anticipated to dip to the east at an angle of approximately 4°.
  - At the eastern end of the B4070 (Ch 0+736), the FEF, overlain by the Hampen Formation, is anticipated to be approximately 10m bgl and 10m thick.

5.12.5 Based on the above observations, to the south of the Shab Hill Barn Fault significantly less limestone of the Great Oolite Group (Hampen and White Limestone Formation) has been encountered than was anticipated based on the British Geological Survey maps. This has resulted in a greater extent of FEF anticipated from the south of the Shab Hill Barn Fault to the end of the scheme.

5.12.6 The scheme would be impacted by the FEF in the form of cuttings within the FEF, with materials to be re-used within the embankments, some of which would be found on areas underlain by the FEF limestone. A more significant extent of the highway subgrade than previously anticipated would be within the FEF. A number of highway structures would either have foundations supported within the FEF or foundations that extend through the FEF into the underlying Inferior Oolite Group.

Description

5.12.7 Where the FEF is generally within 5m of ground level (but less than 5m in places) the mudstone has typically weathered to a firm to very stiff slightly gravelly clay. The gravel comprises mudstone or limestone lithorelicts.

5.12.8 Below this, the FEF is typically an extremely weak to weak grey mudstone, with occasional grey bioclastic limestone beds, which are more frequent higher in the FEF's stratigraphy. Fractures are variously recorded as both undulating and planar, rough and smooth and occasionally infilled with dark grey clay.

5.12.9 The FEF was penetrated fully in three of the exploratory holes associated with the current phases of ground investigation. The full proven thicknesses varied from 9m to 22m. The full sequence of FEF in the area is anticipated to be 20-25m thick, based on several boreholes that proved the thickness to be at least 20m thick, but did not prove both the overlying boundary with the Hampen Formation and the underlying boundary with the IOG. In the boreholes that proved the full thickness of the FEF to the west of the Churn Valley (RC520 and OH411), the FEF was substantially thinner (9-16m thick).

Rock mass quality

5.12.10 The following summarises the rock mass quality for the FEF:

- The average fracture spacing logged in the exploratory holes typically ranges between 50mm and 190mm, with an average of 130mm. (as shown in Appendix F, figure F7.01)
- A similar fracture spacing is recorded in the downhole geophysics which are typically less than 300mm and most commonly about 100mm.

5.12.11 The following features with regards to discontinuities have been observed in the downhole geophysics:

- Bedding discontinuities recorded in boreholes to the south of the Shab Hill Barn Fault commonly dipped in a southerly direction at an angle of about 5°.
- To the north of the Shab Hill Barn Fault, around the Churn valley the following is noted:
  - In DS/RC312 and OH411, which were undertaken on the western side of the Churn Valley, a greater number of easterly dipping bedding discontinuities were encountered that typically dipped at an angle of 15° to 20°.
  - In OH413 which was undertaken to the south of the Churn Valley, a significantly greater proportion of bedding discontinuities dipped in a northernly direction (towards the valley sides) and the bedding discontinuities most commonly dipped at angles between 10° and 25°.

5.12.12 The rock quality designation (RQD) recorded during the logging is summarised in Table 5-12 (refer to Appendix F, figure F7.02). The average and range of RQDs for the entire FEF is presented in Table 5-12 and then spatially with depth and laterally.

Table 5-12 Rock quality designation in the Fuller's Earth Formation

Location within scheme	RQD		
	Lower 20 percentile	Average	Upper 20 percentile
Fuller's Earth Formation - All	16	47	79
South of Shab Hill Barn Fault	13	43	75
North of Shab Hill Barn Fault (DS/RC312, OH411, RC520 and OH413)	27	65	87

5.12.13 The statistics in Table 5-12 show higher RQDs are recorded in the boreholes to the north of the Shab Hill Barn Fault compared to boreholes to the south of the Shab Hill Barn Fault. The boreholes to the north of the fault have logged at least 5m of Great Oolite Group limestone overlying the FEF whereas the boreholes to the south of the fault rarely encountered limestone overlying the FEF.

Engineering properties

Classification

5.12.14 Results of classification testing on samples of FEF are presented below in Table 5-13. The associated plots are presented in Appendix F (refer to figures F7.03 to F7.08).

Table 5-13 Classification testing summary – Fuller's Earth Formation

Property	Range	Average value	Observed trends
Bulk unit weight (kN/m^3)	18 to 23	20	Seven tests on a mixture of material types.
Natural moisture content (%)	2 to 58	21	Spread of data within top 5m that are associated with clay. Below 5m depth predominantly mudstone material with less scatter of results generally between 5 and 12%.
Liquid Limit (%)	39 to 100	62	Limited scatter of plastic limit with depth for both clay (23 tests) and mudstone samples (17 tests). Larger scatter of liquid limit with depth for clay samples (48 to 100%) compared to mudstone samples (39 to 66%). Larger scatter of plasticity index down to 5m associated with clay samples (30 to 65% with average of 44%). Below 5m depth plasticity index scatter reduced to 20% to 40% with an average of 32% associated with mudstone samples. Based on the Atterberg limit chart, FEF range from intermediate to extremely high plasticity. High to extremely high plasticity associated with clay samples (down to around 5m depth). (Note: Atterberg testing conducted in rock samples as the material is logged as extremely weak to weak and laboratory descriptions have indicated clay. Implies that the rock is borderline in terms of soil/rock behaviour)
Plastic Limit (%)	17 to 34	23	
Plasticity Index (%)	20 to 67	39	

Particle Size Distribution

5.12.15 The results of the particle size distributions for 16 samples are shown in Appendix F (refer to figure F7.09) for the FEF. The tests were conducted on samples of FEF predominantly from depths ranging between 0.4 and 3m. The grading curves indicate the material from the test depths to be a slightly sandy silty clay and agree with the logged descriptions. One grading curve indicative of a sandy gravel has been reported from TP605 at 1.5m depth that confirms the logged description of a limestone gravel.

Carbonate content

5.12.16 The results of 29 carbonate content by titration tests are shown in Appendix F (refer to figure F7.10) for the FEF. The results are reported as % CO_2 and higher percentages of CO_2 indicate a higher carbonate content. The following summarises the findings of the carbonate content testing:

- Carbonate contents range from 1.1 to 37% (CO_2) with an average of 21% CO_2
- Low carbonate content (<2% CO_2) have been recorded within the upper metre
- Below 1m depth carbonate content typically ranges from 15 to 25% CO_2

- There is a potential correlation with higher natural moisture contents and PI within the upper two metres with the low carbonate content

Standard Penetration Tests

5.12.17 The results of standard penetration tests within the FEF are presented in Appendix F (refer to figure F7.11). The following summarises the findings of the SPT N_{60} results.

- SPT N_{60} range from 5 to 30 (ignoring outliers associated with gravel and mudstone) with an average value of N_{60} 16. In general, the N_{60} values increase with depth within individual boreholes
- The majority of the SPT N_{60} values are associated with the clay variety of the FEF

Weathered rock strength

Undrained strength

5.12.18 No unconsolidated undrained triaxial tests were conducted. Five consolidated undrained triaxial tests were conducted on samples from the FEF recorded undrained shear strength, c_u, values of 22 to 75 kN/m^2 over depths of 1.4 to 4.8m

5.12.19 Fifteen hand vanes conducted on material retrieved from shallow depths (less than 1m deep) in the FEF recorded peak c_u values of 29 to 106 kN/m^2.

5.12.20 Correlation of c_u with SPT N_{60} [14] indicates a c_u range of 20 to 130 kN/m^2 based on the SPT N_{60} range of 5 to 30 and an f_1 coefficient of 4.5 based on a PI of 44. The predicted c_u range reflects the logged consistency of the material.

5.12.21 A composite plot of the c_u testing and correlations is presented in Appendix F (refer to figure F7.12). There is generally good correlation and c_u generally ranges from 40 to 80kN/m^2 with depth with lower strength and higher strength bands through the depth range.

Drained strength

5.12.22 Small reversed shear box tests were conducted on two recompacted/remoulded samples of the FEF ranging in depths under 2 m below ground level. To supplement the data set three historical shear box tests [20] are included in the data set. The tests were conducted at normal stresses ranging from 20 to 280kN/m^2. Classification testing conducted at the shear box test depths from the current investigation indicate moisture contents of 19 and 27% and a plasticity index of 52%.

5.12.23 The shear box test results are presented in Appendix F (refer to figures F7.13 to F7.16). The range in strength parameters based on the testing are as follows:

Table 5-14 Strength parameters for FEF determined from shear box testing

Strength (based on shear box test)	Effective angle of shearing resistance range (ϕ') (degrees)	Effective cohesion range (c') (kN/m^2)
Peak	24 to 34	5 to 15
Residual	12 to 18	0

5.12.24 Five single stage (100mm diameter sample) consolidated undrained with pore water measurement triaxial tests were conducted on undisturbed samples (UT100, core and dynamic sub samples) from the FEF at depths ranging from 2 to 4.8m. Classification testing conducted at the triaxial test depths indicate moisture contents of 21 to 32% and plasticity indices of 32 to 46%.

5.12.25 The results of the triaxial testing are presented in Appendix F (refer to figure F7.17). The testing suggests the following strength parameter range:

- effective angle of shearing resistance of 32 to 34^o
- effective cohesion (c') of 0 to 5kN/m^2 respectively

5.12.26 The strength parameters from the consolidated undrained triaxial tests are broadly similar to the magnitude of ϕ'_{peak} and c'_{peak} interpreted from the shear box testing.

5.12.27 One residual strength by ring shear tests were conducted on a sample from 5m. Classification testing at the ring shear test depth recorded a moisture content of 35% and a plasticity index of 43%. The test result has been included in the residual shear box strength data (refer to Appendix F, figure F7.16). The data broadly aligns with the upper range of residual strength reported in Table 5-14.

5.12.28 To allow for a comparison of the laboratory based strength testing, constant volume angle of shearing resistance (φ'_{cv}) can be determined for cohesive material using plasticity index values provided in BS8002:2015 [15]. This suggests a φ'_{cv} of 24° (and c' of 0kPa) based on a plasticity index of 44% (based on the average PI from Atterberg Limit testing). This broadly agrees with the interpretation presented Table 5-14 (lower strength range) but is lower than the triaxial testing data.

5.12.29 The residual strength parameter range presented can also be compared against PI as presented by Lupini et al [16]. Based on a plasticity index of 44% (average of the Atterberg Limit testing) a residual shear strength in the order of 10 to 12^o could be anticipated based on Lupini et al [16]. This is located in between the residual strength range presented in Table 5-14.

Intact rock strength

Point Load Index

5.12.30 Point load index tests were undertaken on 80 samples from the FEF. The size corrected results (PLI_{50}) range from 0 to 4MPa and averaged 0.6MPa (refer to Appendix F, figure F7.18).

Unconfined compressive strength (laboratory testing)

5.12.31 Unconfined compressive strength (UCS) laboratory testing was undertaken on two samples from the FEF. The results were 1.8MPa and 6.9MPa. A point load index test was undertaken on one of the UCS test samples that recorded an $Is_{(50)}$ of 0.4MPa. The corresponding UCS test result was 1.8MPa which is 4.5x the $Is_{(50)}$ result.

5.12.32 Based on the single point load index to UCS correlation of 4.5, the average UCS based on the average $Is_{(50)}$ would be 2.7MPa and the maximum based on an $Is_{(50)}$ of 4MPa would be 18MPa. This would correspond to a weak rock strength [18].

5.12.33 Based on the typical engineering descriptions which range from extremely weak to weak, UCS is anticipated to range between 0.6 to 10MPa [18].

Rock mass strength

5.12.34 Rock mass parameters have been derived using the Hoek Brown criterion [21]. The rock mass parameters for the intact material is as follows (for the purposes of design, parameters should be developed in a location specific basis):

- φ' = 10 to 20^o
- c' = 5 to 20kPa

5.12.35 This is based on the following input parameters:

- UCS = 1.5MPa
- GSI = 15 to 40 (range of discontinuity conditions, low GSI to represent risk of high plasticity clay infill to discontinuities)
- Mi = 5 (mudstone)
- D = 0.7 (mechanical excavation)
- MR = 150 (mudstone)
- Cut height of 9.5m

Stiffness

Weathered rock stiffness

5.12.36 Undrained and drained Young's Modulus (E_u and E') for the FEF have been based on the correlation for cohesive materials presented in CIRIA 143 [14].

- $E_u = 1.1 \times N_{60}$ (MPa)
- $E' = 0.9 \times N_{60}$ (MPa)

5.12.37 Based on the SPT N_{60} range of 5 to 30, the following E_u and E' ranges would be anticipated:

- E_u = 6MPa to 30MPa (average 17MPa)
- E' = 5MPa to 25MPa (average 15MPa)

Rock mass stiffness

5.12.38 Rock mass stiffness (E_m) has been estimated using the equation $E_m = jM_rq_{uc}$ based on intact rock strength and discontinuity spacing (BS8004:1986 [19]).

5.12.39 For the intact material, a derived intact compressible strength (q_{uc}) of 2.5MN/m^2 has been used. An Mr value of 150 has been selected (corresponding to cemented mudstone (Group 2 Table 4 and Appendix A of BS8004:1986 [19])). Based on the RQD and fracture spacing, the rock would be classified as poor quality therefore the value of j=0.1, yielding a rock mass stiffness of 35MN/m^2.

Compaction

5.12.40 Five dry density versus moisture content relationship tests (using a mix of the 2.5 and 4.5kg hammers) were undertaken on FEF from depths ranging from 1 to 2.7m. Optimum Moisture Contents (OMC) of 17% to 25% with an average of 20% were recorded and corresponding maximum dry densities ranging from 1.52 to 1.81 Mg/m^3.

5.12.41 Two sets of CBR tests were undertaken on samples of FEF from depths of 0.9 and 1.2m. CBR values drop with increasing moisture content from a CBR of around 19% at moisture contents of 17%, down to a CBR of 4% around a moisture content of 23% (refer to Appendix F, figure F7.20 and F7.21). One historical CBR test close to the scheme [20] recorded a CBR of 2.2% at a moisture content of 33%.

5.12.42 Based on historical holes near the scheme [20] moisture condition values (MCV) of 8.7 to 10.2 were recorded at moisture contents of 29 to 36%. Hand shear vanes and a pocket penetrometer recorded at the test depths recorded peak undrained shear strengths ranging from 50 to 90kN/m^2.

Permeability

5.12.43 The Fuller's Earth Formation is a low permeability mudstone which separates Great Oolite Group limestones from the underlying Inferior Oolite Group. The formation exhibits little fracturing and where limestone beds are present, the fractures are typically infilled. Two variable head tests were completed in the Fuller's Earth Formation, indicated a K value range between 2x10^{-7} and 1.3x10^{-7} m/s [2].

5.12.44 The results are discussed in further detail within the hydrogeological interpretation presented in Section 5.17.

5.13 Inferior Oolite Group

General

5.13.1 The Inferior Oolite Group (IOG) was encountered in 70 exploratory holes of which 42 exploratory holes are associated with the Phase 1 and Phase 2A ground investigations. The location of the IOG is presented in plan on drawing HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 and in section on the geological long sections (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010) in Appendix J.

5.13.2 As part of the recent phases of ground investigation, the IOG has been split into the three formations that form the IOG, namely: the Salperton Limestone Formation (located at the top of the IOG), the Aston Limestone Formation and the Birdlip Limestone Formation (located at the bottom of the IOG).

5.13.3 The following is a summary of the IOG occurrence from the ground investigation:

- Ch 1+750 to Ch 2+050 (refer to Appendix E Conceptual Section E)
  - The edge of the Cotswold escarpment is located at approximately Ch 1+750 and is formed from the Birdlip Limestone Formation. This was reflected in the boreholes between Ch 1+750 and Ch 2+050 which encountered the Birdlip Limestone Formation either at surface (which increases from 205mOD to 240mOD over this extent) or underlying Head deposits. The base of the IOG (Birdlip Limestone Formation) was typically between 205mOD and 210mOD. The Shab Hill Fault crosses the scheme at approximately Ch 1+950 where a region of lower rock mass quality can be observed in the Birdlip Limestone Formation, but there is little throw apparent in the base of the unit. The fault plane has not been identified in the ground investigation to date, but being a normal fault is assumed to dip to the south at an angle of greater than 60°.

- Ch 2+050 to Ch 2+600
  - The ground level rises approximately 35m and there is a gap in the ground investigation data. Additional ground investigation has been recommended in this area as defined in the Annex A Addendum [4].
- Ch2+600 to Ch 2+950
  - Throughout this section of the alignment the ground level plateaus relative to the lower chainages, rising just 5m between Ch 2+600 and Ch 2+950. The Aston Limestone Formation (overlying the Birdlip Limestone Formation) is anticipated to subcrop (rock surface underlying superficial deposits) at approximately Ch 2+600 and the Salperton Limestone Formation (overlying the Aston Limestone Formation) is anticipated to subcrop between Ch 2+600 and Ch 2+870. Between Ch 2+870 and Ch 2+950 the IOG (Salperton, Aston and Birdlip Limestone Formations) underlies the Fuller's Earth Formation, which thickens with increasing chainage. The sequence from the Fuller's Earth Formation through to the Birdlip Limestone Formation was observed in RC516.
- Ch 2+950 to Ch 3+500 (refer to Appendix E Conceptual Section G)
  - The Shab Hill Fault crosses the proposed alignment at approximately Ch 2+950. It is downthrown to the south by some 18m. The relative movement can be seen in the boreholes, with the top of the IOG at approximately 275mOD (at ground level) to the north of the fault and 258mOD (~20m bgl) to the south of the fault.
  - A newly identified fault, which has been named the Churn Valley Fault crosses the alignment at Ch 3+180. It is also downthrown to the south, with borehole evidence indicating that the top of the Inferior Oolite Group to the south of this fault is approximately 10m lower at approximately 248mOD.
  - The Shab Hill Barn Fault (refer to Section 5.2) crosses the alignment at approximate Ch 3+500, with downthrow to the north. The Shab Hill Barn Fault and Shab Hill Fault to the north define a downthrown block of strata or 'graben' structure. This is illustrated on Section G in Appendix E.
- Ch 3+500 to Ch 5+500
  - To the south of the Shab Hill Barn Fault, the upper level of the IOG is assessed to be at approximately 270mOD (~10m bgl) and progressively deepens with increasing chainage until at Ch 4+700 the Stockwell Fault is encountered.
  - The Stockwell Fault has been assessed to be downthrown to the north by some 30m. On the northern side of the Stockwell Fault the top of the IOG is estimated based on borehole records to be at 40m bgl (~230mOD) and to the south approximately 10m bgl (~260mOD).
  - To the south of the Stockwell Fault the top of the IOG increases in depth with increasing chainage. On the basis of the topography, the regional dip of the stratigraphy and the nearest borehole (DSRC403) at Ch 5+500 the IOG is estimated to be at approximately 30m bgl (~225mOD).

5.13.4 The scheme would be impacted by the IOG in the form of cuts that vary in depth from 2m to 22m between Ch 1+750 and Ch 3+050 and along the B4070 side road. At Shab Hill, part of the embankment associated with the junction would be founded over the IOG. To the south of Ch 3+300 the scheme proposals are not likely to impact the IOG.

General description

5.13.5 Where the limestone of the Inferior Oolite Group is exposed at surface (Ch ~1+750 to Ch ~2050), it has typically weathered to a brown gravelly sandy clay that is between 0.3m and 1.5m thick. This material is interpreted as completely weathered rock and is considered in Section 5.10.

5.13.6 Typical descriptions of the IOG encountered during the ground investigations are presented in Table 5-15. The typical descriptions in Table 5-15 have been presented for the three formations that comprise the IOG within the scheme.

Table 5-15 Typical descriptions of the Inferior Oolite Group

Inferior Oolite Group formation	Typical description	Thickness (m)
Salperton Limestone Formation	Very weak to strong yellowish brown/grey oolitic, bioclastic and sometimes crystalline limestone. Bedding discontinuities typically sub horizontal (but joints were encountered up to 50°), undulating, rough and close to medium spaced. Voids of up to 80mm, often infilled with clay, were described in a few of the cores.	6.5 – 11.5m Average: 9m
Aston Limestone Formation	Weak to strong light brown/grey bioclastic limestone. Bedding discontinuities typically sub horizontal (but joints were encountered up to 50°), undulating, rough and close to medium spaced. Voids of up to 30mm were described in a few of the cores.	0.5 – 5.2m Typically: 1 – 3m Average: 2m
Birdlip Limestone Formation	Very weak to strong light yellowish brown bioclastic limestone. Bedding discontinuities typically sub horizontal (but joints were encountered up to sub vertical), undulating, rough and close to medium spaced. Voids of up to 1m in size have been identified, both open voids and voids infilled with clay are described in the logs and televiewer.	49 – 55m Average: 52m

5.13.7 For the purposes of this GIR, the Inferior Oolite has been divided to the three Formations tabulated above. The British Geological Society (BGS) Stratigraphical Report includes even more detailed logging of selected boreholes that encountered the IOG (refer to Appendix C). Within the BGS report, the IOG stratigraphical members (as presented in Table 3-1) were further differentiated to an informal subdivision of selected members (refer to Table 1 in Appendix C).

5.13.8 The BGS report states that the Crickley member of the Birdlip Limestone Formation in particular the Pea Grit subdivision shows signs of greater karstification – with more significant dissolution voids present at the base of this sequence. In addition, poorer rock mass quality is likely to be associated with the Pea Grit Member.

Presence of voids

5.13.9 Open and infilled voids have been recorded within the IOG. associated with both extension cambering processes (gulls), and dissolution of limestone (karst features, dissolution voids).

5.13.10 The borehole log descriptions have recorded voids of up to 210mm, which were often infilled with clay were reported in the borehole logs throughout the IOG (as presented in Table 5-15). To further supplement the logging information, down hole geophysics data has been used to assess the presence of voids in the IOG (namely optical televiewer and calliper measurements)

5.13.11 The location of voids identified from the logging and those identified from the downhole geophysics from Ch1+750 to Ch 2+000 is presented in the long section for this extent in Appendix E, Section E. The following summarises the main observations based on the long section mark up:

- Voids within the IOG are present throughout the IOG sequence as clusters up to 5m in depth at various levels with the exception of RC508 that logged voids throughout the borehole core.
- Voids are more common and larger close to interface between the Birdlip Limestone Formation and the underlying Bridport Sand Formation.
- Voids, identified as dark shadows on the optical televiewer and with high values on the calliper measurement, of up to a metre in length have been identified.

5.13.12 Note that additional boreholes with downhole geophysics have been proposed between Ch 2+100 and Ch 2+600, where GI access has not been possible to date (This additional recommended ground investigation has been defined in the Annex A Addendum [4]).

5.13.13 Open voids and fractures were observed in the outcrops of the IOG, with apertures of more than 200mm (refer to Appendix B). An infilled 'gull' 2 to 3m wide was identified at Outcrop 2.

5.13.14 The potential presence of infilled 'gulls' has been identified in several the boreholes. The table below provides a summary.

Table 5-16 Borehole locations with potentially infilled gulls

Borehole	Geological feature and potentially evidence of gulls
DS/RC302	1.7 to 8.2m bgl extremely weak, very weak and weak limestone with common fractures with orange staining and orange-stained infill. Voids up to 20mm. Assessed zone of core loss at 7.75m bgl and 1m of core loss from 24.7m bgl (potential presence of a gull)
RC508	2.1 to 8.3m bgl weak limestone with frequent zones of calcite infill of fractures (up to 110m), orange-brown fracture staining and clay infill. Voids up to 40mm. Assessed zones of core loss from 16.2 to 17.7m bgl underlying limestone with voids (up to 15mm) – (potential presence of a gull)
DS/RC/OH110	From 1.4m bgl to 12.2m bgl, medium-strong, weak and very weak limestone, with orange-brown stained fractures (including slickensides). Fractures infilled with clayey fine- and medium sand. Abundant voids, up to 1000mm, infilled with orange clay from 12.2m bgl. Assessed zones of core loss (at least 0.5m) from 19.1m bgl and 22,2m bgl. At 32.0m bgl and 33.8m bgl probable voids noted by driller, close to the base of the Inferior Oolite Group. Possibly indicates enhanced dissolution at the contact with the underlying Lias Group

5.13.15 Surface geophysics undertaken from Ch 1+750 to Ch 1+950 [3] identified two areas with lower resistivity than the surrounding material that may represent a potentially infilled void. Additional trial trench investigation of these locations is recommended, as defined in the Annex A Addendum [4].

5.13.16 The A417 Birdlip Bypass ground investigation [22] and the A417 Birdlip Bypass Geotechnical Feedback Report [23] recorded the following:

- Potential gulls within two trial pits located immediately to the south of the existing Air Balloon roundabout (approximately Ch 2+100). The trial pit logs record limestone and a near vertical fracture beyond which an infilled gull is interpreted. The infill is recorded as a gravelly clay but no records on the width of the feature are shown on the logs [22].
- The Barrow Wake cut south of Air Balloon roundabout recorded numerous vertical fissures 20 to 300mm wide within the cut [23].
- Fissures (likely gulls) 300mm and at least 17m deep were encountered at the foundation level for the Barrow Wake portal structure [23].

Rock mass quality

Borehole evidence

5.13.17 The average fracture spacing recorded in cores from the IOG typically ranges between 70mm and 280mm with an average of 190mm (refer to Appendix F, figure F8.01). The fracture spacing increases with depth up to about 10m bgl. For depths greater than 10m bgl there is no discernible trend.

5.13.18 When plotting the average fracture spacing against height above the base of the Birdlip Limestone Formation (refer to Appendix F, figure F8.02) the following observations are made:

- slightly wider fracture spacings are recorded near the top and base of the Birdlip Limestone Formation.
- slightly closer spacings in the Salperton Formation, the Aston Formation and the middle of the Birdlip Limestone Formation.

5.13.19 The rock quality designation (RQD) averages and range recorded during the logging is summarised in Table 5-17 for the IOG as a whole, for the IOG between Ch1+750 and Ch 2+050 and for each of the three IOG formations (refer to Appendix F, figure F8.03).

Table 5-17 Rock quality designation in the Inferior Oolite Group

Inferior Oolite Group formation	RQD		
	Lower 20 percentile	Average	Upper 20 percentile
Inferior Oolite Group combined	35	65	93
Inferior Oolite Group (Ch 1+750 to Ch 2+050)	15	45	74
Salperton Limestone Formation	52	71	96
Aston Limestone Formation	46	64	87
Birdlip Limestone Formation	34	63	93

5.13.20 Based on the recorded RQD values the following can be observed:

- RQD is generally lower in the limestone between Ch 1+750 and Ch 2+050. The IOG over this extent is crossed by the Shab Hill Fault and is near the escarpment edge.

- The Aston and the Birdlip Limestone Formations both recorded slightly lower average RQDs compared to the Salperton Formation. However, there is much less data for the Aston and Salperton Formations compared to the Birdlip Limestone Formation.
- For RQD plotted against depth above the base of the IOG (refer to Appendix F, figure F8.04) the Birdlip Limestone Formation has recorded a larger scatter of RQD (generally from 10 to 90% between 10m to 30m above the base of the IOG. Above and below this depth the RQD scatter generally reduces to around 60 to 90%. This corresponds with the average fracture spacing observations.

Downhole and surface geophysics evidence

5.13.21 Discontinuities identified in the down hole geophysics within the IOG were typically spaced at less than 500mm and most commonly between 50mm and 200mm. The discontinuities were predominantly closed, but rare open discontinuities were recorded of up to 230mm.

5.13.22 The dip and dip direction data suggests the discontinuities most commonly dip towards the south and represent bedding discontinuities but there is considerable variability. The dip angle recorded ranged from less than 1° to 84° but was typically less than 20°.

5.13.23 The surface geophysics, namely the seismic (S wave) survey provide an indication on the rock mass quality of the IOG from Ch 1+750 to Ch 2+100 (in the Birdlip Limestone Formation). Interpretation of the seismic velocities for the full IOG sequence has been made rather than individual formations due to coarse nature of the results. Appendix C presents the interpretation of the S wave data and the main findings are summarised below:

- The upper 8 to 10m seismic velocities (S wave) range from 500 to 900m/s below which velocities increase to >1000m/s. The lower velocity range corresponds to the lower RQDs over this depth range.
- Approaching the Shab Hill Fault, S wave velocities below 8 to 10m decrease to around 800m/s and correspond to the low RQDs within the boreholes approaching the fault.
- The reduction in S wave velocity approaching the Shab Hill Fault agrees with the lower RQDs and increased fractures within the boreholes over the same extent.

Engineering properties

Classification

Natural moisture content

5.13.24 Six moisture content tests were undertaken on samples from the IOG: two in the Salperton Formation, one in the Aston Formation and three in the Birdlip Limestone Formation (refer to Appendix F, figure F8.05). The moisture content values ranged from 7% to a maximum of 19% with an average of 14%. Twenty moisture content tests were undertaken on rock sample from the IOG (all from the Biirdlip Limestone Formation) that ranged from 2% to 15% (refer to Appendix F, figure F8.06).

Bulk unit weight

5.13.25 Bulk unit weight was recorded from 32 IOG samples and recorded a range from 22 to 25kN/m^3 and an average of 24kN/m^3 (refer to Appendix F, figure F8.07).

Particle Size Distribution

5.13.26 Ten particle size distribution tests were conducted on samples from less than 1m depth (except for sample taken at 4.2m depth) (refer to Appendix F, figure F8.08). The results record the material as a slightly silty sandy gravel. It is interpreted that the material tested is completely weathered rock.

Standard Penetration Tests

5.13.27 Forty-four standard penetration tests (SPT N) were undertaken in the IOG: one in the Aston Limestone Formation and 39 in the Birdlip Limestone Formation. A large range in SPT N has been recorded (N 34 to N>1000) (refer to Appendix F, figure F8.09). A grouping of SPT N values from N 34 to N 150 has been recorded between 15m to 25m above the base of the IOG (refer to Appendix F, figure F8.10).

Point load index

5.13.28 Point load index tests were undertaken on 533 samples of the IOG (refer to Appendix F, figure F8.11 and F8.12): 70 in the Salperton Limestone Formation, 12 in the Aston Limestone Formation and 451 in the Birdlip Limestone Formation. The results for each formation range as follows.

- Salperton Limestone Formation: 0 to 3.6MN/m^2, average 1.0MN/m^2
- Aston Limestone Formation: 0 to 2.2MN/m^2, average 0.8MN/m^2
- Birdlip Limestone Formation: 0 to 4.4MN/m^2, average 0.95MN/m^2

Intact rock strength

5.13.29 Unconfined compressive strength (UCS) laboratory testing was undertaken on 31 samples from the IOG: five in the Salperton Limestone Formation, none in the Aston Limestone Formation and 26 in the Birdlip Limestone Formation (refer to Appendix F, figure F8.13 and F8.14). The results for the two formations tested range as follows.

- Salperton Limestone Formation: 2.8 to 16.6MN/m^2, average 7MN/m^2
- Birdlip Limestone Formation: 3.6 to 32.1MN/m^2, average 15MN/m^2

5.13.30 The correlation between UCS values and point load test results has been reviewed by comparing UCS test results with point load test results undertaken on the same sample (refer to Appendix F, figure F8.15). This has resulted in the assessment being carried out on 12 UCS tests for the Birdlip Limestone Formation only. Point load index to UCS factors generally ranging from 5 to 30 have been recorded (ignoring one outlier of 54) with an average of 20. When plotted with depth, a lower correlation of 5 to 10 is recorded for the upper 30m and a higher correlation of 20 to 30 for the bottom 20m.

5.13.31 One tensile strength test was conducted on a sample of the IOG as part of the Phase 1 ground investigation. It recorded a tensile strength of 2.6MPa.

5.13.32 The results of the intact rock tests suggest that the IOG is very weak (1 - 5MPa) to medium strong (25-50MPa) in accordance with the description for rock strength provided in BS5930:2015 [18]. This is broadly in line with the descriptions provided on the geological logs, which range from extremely weak to strong. The UCS to point load correlations suggested in Section 5.13.31 predicts that the Birdlip Limestone Formation is very weak to weak over the upper 30m and ranges from weak to medium strong towards the bottom 20m (refer to Appendix F, figure F8.16).

Rock mass strength

5.13.33 Rock mass parameters have been derived using the Hoek Brown criterion [21]. Typical rock mass parameters for the intact material is as follows (for the purposes of design, parameters should be developed in a location specific basis):

- φ' = 30 to 40°
- c' = 60 to 120kPa

5.13.34 This is based on the following input parameters:

- UCS = 5 to 25MPa
- GSI = 40 (rock structure is assumed to be blocky, disturbed (many intersecting joint sets) and the surface condition of the discontinuities as fair (smooth, moderately weathered and altered surfaces))
- Mi = 9 (sparry limestone)
- D = 0.7 (mechanical excavation)
- MR = 600 (sparry limestone)
- Cut height of 22m (that the cut height varies within the IOG and location specific values may need to be considered for design)

Joint shear strength

5.13.35 One shear box test was undertaken on a shear plane within a core sample of the IOG (Birdlip Limestone Formation) (refer to Appendix F, figure F8.17 and F8.18). The sample was from DS/RC404 at 27.0-27.5m bgl and is described as "*Medium strong yellowish brown and light brown limestone. Moderately to slightly weathered. Natural shear plane with no infill material. Joint roughness coefficient = 10-12. Debris is fine to coarse gravel and sand.*"

5.13.36 The peak angle of shearing resistance was 35°, with a cohesion of 25kPa. The residual angle of shearing resistance was 28.5°, with a cohesion of 15kPa.

Rock mass stiffness

5.13.37 Youngs Modulus was measured as part of a UCS test conducted on one sample of IOG (Birdlip Limestone Formation) from DSRC406 at 28.15m depth. A Youngs Modulus of 5800 MN/m^2 was recorded (at 50% of the failure load) that recorded a UCS of 17MN/m^2.

5.13.38 Rock mass stiffness (E_m) has been estimated using the equation $E_m = jM_rq_{uc}$ based on intact rock strength and discontinuity spacing (BS8004:1986 [19]).

5.13.39 For the intact material, an unconfined compressible strength (q_{uc}) of 10MN/m^2 has been used. An M_r value of 300 has been selected (corresponding to oolitic limestone (Group 2 Table 4 and Appendix A of BS8004:1986 [19]). Based on the RQD and fracture spacing, the rock would be classified as poor quality therefore the value of j=0.2, yielding a rock mass stiffness of around 600MN/m^2. As presented in Section 5.12.31 the IOG rock strength will vary from very weak to medium strong. As such, there is likely to be a range in rock mass stiffness and location specific values may need to be considered for design.

Groundwater flow

5.13.40 Groundwater flow through the Inferior Oolite Group is dominated by porosity caused by a combination of extensional features, fracturing, faulting and chemical dissolution, has led to the development of large opening, including metre scale voids locally. Greater porosities appear to be present towards the base of the formation where groundwater flows occur with high aquifer transmissivity. Four variable head tests were completed in the Inferior Oolite Group, indicated a K value range between $2x10^{-6}$ and $7.2x10^{-5}$ m/s ([2] and [3]). Variable head testing was attempted at an additional three locations, DSRC109, DSRC301 and DSRC302, however due to the response zone not being fully saturated, a valid hydraulic conductivity value could not be estimated.

5.13.41 The results are discussed in further detail within the hydrogeological interpretation presented in Section 5.17.

Aggregate testing

5.13.42 The Los Angeles coefficient for the fragmentation of aggregate was calculated from testing on 12 samples from the Inferior Oolite Group. The minimum value was 36, the maximum was 58 and the average was 50.

5.14 Lias Group

General

5.14.1 As presented in Table 3-1 the Lias Group comprises the following Formations:

- Bridport Sand Formation
- Whitby Mudstone Formation
- Marlstone Rock Formation
- Dyrham Formation
- Charmouth Mudstone Formation

5.14.2 Where encountered, the Lias Group underlies the Cheltenham Sands and Gravels, Mass Movement Deposits, or the Inferior Oolite Group (below the escarpment).

5.14.3 The earthworks proposed for the scheme would not directly encounter the Lias Group. The scheme is located on embankment over the Cheltenham Sands and Gravels and the Mass Movement Deposits (Ch 0+000 to Ch 1+700) or within cut in the Inferior Oolite Group (Ch 1+700 to Ch 3+000). Structures associated with Grove Farm Underpass and the Cotswold Way Crossing may require foundations extending into the Lias Group. Beyond the scheme boundary along Crickley Hill, the Lias Group below the Mass Movement Deposits may have undergone deeper seated movements associated with the escarpment formation. This is discussed in further detail in Section 7.4.

5.14.4 Hutchinson (1991) [11] provides an outline summary of the anticipated thickness of the Lias Group in the region of Crickley Hill as summarised below:

- Upper Lias (including the Bridport Sand Formation and Whitby Mudstone Formation): 60 to 75m thick

- Middle Lias (including the Marlstone Rock and Dyrham Silts): 50 to 60m thick

5.14.5 The logging of the exploratory holes by GEL has subdivided the Lias Group into formations as presented in Section 5.14.1. Within the description section of this report the Lias Group has been treated as two units, the Bridport Sand Formation and the underlying Lias Group mudstones. (It is considered reasonable to combine the Lias Group mudstones into a single description as there is little distinction in material properties of the Whitby Mudstone Formation, Dyrham Formation and Charmouth Formation, based on the log descriptions and the laboratory testing undertaken. The Marlstone Rock Formation is a relatively thin limestone and sandstone bed that is stratigraphically located between the Whitby Mudstone Formation and the Dyrham Formation so forms part of the Lias Group.

The Marlstone Rock is a distinct marker bed across the Cotswold (as suggested by the BGS, refer to Appendix C). Hutchinson [11] states that the Marlstone Rock may be present within Normans Brook causing an irregular stream profile at around chainage Ch 1+250 with a reduced level of around 165.2m AOD. The location of the Marlstone Rock Formation is discussed in the description section in Section 5:16 .

5.15 Lias Group – Bridport Sand Formation

General

5.15.1 The Bridport Sand Formation (BDS) has been identified in 27 exploratory hole locations (five historical, four Phase 1 and 18 Phase 2A). The location of the BDS is presented on the geological long sections (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010) in Appendix J.

5.15.2 The following summarises where within the scheme extents the BDS has been identified based on the ground investigation conducted to date:

- Predominantly encountered between chainage Ch 1+750 and Ch 2+500, where the alignment traverses the south eastern perimeter of Crickley Hill and Cotswold escarpment. The upper surface of the unit in this location was encountered between 217 and 190m AOD. The logged upper surface suggests that the upper surface of the BDS decreases in elevation towards the south and south east.
- The Cotswold Way (two boreholes)
- Within several boreholes in the southern part of the scheme between chainage Ch 3+500 and Ch 5+000. The upper surface of the BDS was identified in DSRCOH400 at 77mbgl (191m AOD) which is located at chainage 4+800.

5.15.3 The earthworks proposed for the scheme would not directly encounter the BDS. From Ch 1+750 to Ch 2+500 the scheme is in cut within the Inferior Oolite Group. Towards Ch 1+750 it is anticipated that the centreline of the scheme would be less than a metre from the top of the BDS, and hence it may be encountered in the road sub-formations in this area. Beyond Ch 1+750, the scheme alignment rises up the stratigraphic sequence and the BDS at increasingly depths. The Cotswold Way Crossing structure may require piled foundations extending into the BDS.

5.15.4 The location of the BDS relative to the scheme alignment is illustrated on the geological long sections across the scheme (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007 to -000010) in Appendix J.

Description

5.15.5 The lithological descriptions vary across the BDS. The most dominant component based on the borehole descriptions is micaceous silt, silty/sandy clays, and silty sand, followed by micaceous siltstones and mudstones. Subordinate sandstone and limestone beds are noted within the sequence but are much less common in occurrence. Based on the frequency of occurrence within the borehole logs, the following descriptions of the BDS are considered typical:

- Light to dark grey clayey micaceous silt and clay (occasionally described as fissured, orangish brown fine-grained sand with light to dark grey and dark-yellowish brown laminated mudstones and siltstones which locally tends to silty and sandy clay. Occasional thin beds of bioclastic limestone and sandstone.
- Very weak to weak light to dark grey laminated predominantly sandy and silty micaceous siltstones and dark grey/dark yellowish-brown micaceous mudstones. Common subvertical joints recorded. Interbeds of silty and sandy clays are common. Thin interbedded bioclastic limestone noted in DSRC315, RC507 and DSRCOH400.

5.15.6 The PSSR [5] indicates that the BDS is generally 20 to 25m thick. Where the BDS has been fully penetrated the borehole logs (seven number) generally support this reporting a range of 10 to 28m and an average thickness of 19m. Nineteen of the boreholes did not penetrate the BDS and recorded non penetrated thicknesses of 1m to 37m. From chainage Ch 1+500 to Ch 2+100 the BDS appears to generally increase in thickness from around 18m in the south west to around 26m in the north east.

5.15.7 The thickness of the BDS was not proved to the south of the scheme. The BDS was encountered up 30m thick in DSRCOH414 but the base was not proven.

5.15.8 The downhole geophysical data has been used to supplement the logged descriptions of the BDS. Particular focus was given to reviewing gamma emissions in the BDS based on the recommendations provided by the BGS (refer to Appendix C). The results of the gamma density and calliper geophysics were also used to infer discontinuity profiles/ potential voids within the BDS. The following summarises the main findings:

- The results of the differential gamma emissions from boreholes DSRC404, DSRC408, DSRC419, DSRC110, DSRC302, DSRC303, DSRC109, DSRC301 and DSRC319 indicate that there is a clear correlation of higher and sustained levels of natural gamma in the BDS. From the top surface of the Bridport Sand Formation, the natural gamma emissions recorded increase fourfold compared to the strata above.
- The calliper survey indicates that there are notable changes in the borehole diameter at certain depths within the BDS. This is particularly prominent in boreholes DSRC301, DSRCOH304 and DSRC319:
  - In DSRC301 at the top of the BDS there is an increase in calliper diameter from 200mm (constant borehole diameter) to 600-700mm from 25-26mbgl, corresponding to slightly sandy silt. This coincides with a Long and Short

Spaced Density decrease. A review of the downhole Optical Image at this depth indicates the presence of a void which appears to be a major fracture or fissure based on the geophysical classification of discontinuities. A review of the borehole log and core photographs in this location does not indicate any extensive voiding. The feature does not extend above into the Inferior Oolite. This feature may represent a large void or may be the result of the borehole being flushed/washed out prior to the downhole geophysical survey being undertaken.

- In DSRC319, there is an increased calliper diameter at ~27mbgl within extremely weak/very weak fractured siltstone that corresponds to a Long and Short Spaced Density decrease. The acoustic image provided by the geophysical survey indicates potential voiding within the rock mass at this depth. This feature is located approximately 5m below the boundary with the Inferior Oolite and does not extend into this formation.
- Similar potential voiding is also suggested in extremely weak/very weak fractured siltstone in DSRCOH304 at approximately 37mbgl.

5.15.9 The results of the calliper diameter geophysical surveys indicate that there is the potential to encounter voids within the BDS, particularly within the extremely weak/very weak fractured siltstone units.

Rock mass quality

5.15.10 The Rock Quality Designation (RQD) recorded during the logging is summarised in Table 5-18 below for boreholes within 200m of the escarpment edge and beyond 200m from the escarpment edge (refer to Appendix F, figure F9.01).

Table 5-18 Bridport Sands Formation rock quality designation (RQD) summary

Strata	RQD		
	Lower 20 percentile	RQD average	Upper 20 percentile
Bridport Sands Formation (boreholes located within 200m of Cotswold escarpment) – 12 boreholes	20	49	85
Bridport Sands Formation (boreholes located >200m from Cotswold escarpment) – 8 boreholes	57	75	95

5.15.11 The results indicate that the RQD is much higher on average in boreholes located further away from the Cotswold escarpment. The reduction in RQD towards Cotswold escarpment could be attributed to cambering resulting in disturbance of the BDS.

5.15.12 Based on the information provided on borehole logs, fracture spacing in the BDS is summarised per rock type in Table 5-19 (refer to Appendix F, figure F9.02).

Table 5-19 Bridport Sand Formation fracture spacing summary

Rock type within BDS	Fracture spacing (mm)		
	Lower 20 percentile	average	Upper 20 percentile
Mudstone	100	253	340
Sandstone	74	152	216
Siltstone	128	216	226

5.15.13 The following summarises the discontinuity information within the BDS:

- Discontinuities identified from the downhole geophysics spaced between 20mm and 1500mm, but typically ranged from 20mm to 650mm with an average spacing of around 210mm (based on the typical range).
- Based on the downhole geophysical surveys, the discontinuity orientation (azimuth) was highly variable, although it can be seen that the most common dip direction is towards the east. The discontinuity dip angle was also highly variable, ranging between <1° and 84°, however the dip angle of the discontinuities was typically less than 20° and this is interpreted to represent bedding.
- Based on the down hole geophysics the discontinuities were predominantly closed, but rare open discontinuities recorded apertures up to 63mm (DSRCOH304).
- Occasional infilled discontinuities logged in the boreholes infilled with clay, between 10 and 50mm in thickness and rarely calcite, silt and stained.

Engineering properties

Classification

5.15.14 Results of classification testing on samples of the BDS are presented below in Table 5-20 and the associated plots are presented in Appendix F (figures F9.03 to F9.07).

Table 5-20 Classification testing summary – Bridport Sand Formation

Property	Range	Average value	Observed trends
Bulk unit weight (kN/m^3)	19.7 to 24	22	
Natural moisture content (%)	11 to 25	15	Moisture contents of the soil (24no.) and rock (16no.) components of the BDS generally have a similar scatter of data. When plotted against m AOD following can be observed: • 11 to 25% range in moisture content recorded over the upper 10 to 15m of the BDS. • Potential reduction in moisture content to 13% over the bottom 10m of the BDS.
Liquid Limit (%)	31 to 47	36	Atterberg Limits of the soil (17no.) and rock (14no.) components of the BDS generally have a similar scatter of data.
Plastic Limit (%)	17 to 26	22	Plastic limit with depth generally constant but a slight reduction in depth is recorded. Similar reduction in depth of liquid limit (higher scatter due to six samples with liquid limit greater than 40% at varying depths). Plasticity index follows a similar slight reduction in depth with higher values (above 20%) associated with the higher liquid limit samples.
Plasticity Index (%)	9 to 26	15	Based on Atterberg Limit chart BDS is of low to intermediate plasticity clay. Two samples indicate an intermediate plasticity silt.

Particle Size Distribution

5.15.15 Seven particle size distribution tests were conducted on BDS samples from depths ranging from 25 to 40m (refer to Appendix F, figure F9.08). The testing indicates the material is generally slightly clayey to clayey slightly sandy silt.

Standard Penetration Tests

5.15.16 The results of standard penetration tests within the BDS are presented in Appendix F (refer to figure F9.09). The following summarises the findings of the SPT N_{60} results.

- SPT N_{60} range from 16 to 655 with an average value of N 255. In general, the N_{60} values increase with depth within individual boreholes
- Five SPT N_{60} results are recorded within the soil variety of the BDS (silt) and recorded SPT N_{60} values of 16 to 104. The remaining SPT N_{60} tests were conducted in the rock of the BDS and recorded an SPT N_{60} range of 114 to 655. In general, for the rock, a slight increase of SPT N_{60} with depth can be observed with a number of elevated results (above SPT N_{60} 350) at varying depths

Strength parameters

Undrained strength

5.15.17 No laboratory testing to determine undrained strength was undertaken on the BDS.

5.15.18 Four hand vanes were undertaken on samples of BDS (within the silt/clay material) that recorded peak undrained shear strengths of 68 to 140 kN/m^2. This range generally corresponds with the logged firm to very stiff consistency.

Drained strength

5.15.19 Two direct shear tests on silt and siltstone samples of the BDS from DSRC406 and DSRC408 from 31 to 38.1m depth were undertaken. The samples were sheared at normal stresses ranging from 100 to 850kN/m^2 up to displacements of 8mm. Based on the test results presented in Appendix F (refer to figure F9.10) the following shear strength parameters are interpreted.

- effective angle of shearing resistance of 30^o
- effective cohesion (c') of 30kN/m^2

5.15.20 Three single stage consolidated undrained triaxial with measurement or pore pressure tests on silt samples of the BDS from DSRC301 were undertaken. One of the samples (35.1m depth) was not taken to failure due to limits of the testing cell. Based on the limited test results presented in Appendix F (refer to figure F9.11) the following shear strength parameters are interpreted.

- effective angle of shearing resistance of 35^o
- effective cohesion (c') of 0kN/m^2

5.15.21 To allow for a comparison of the laboratory based strength testing, constant volume angle of shearing resistance (φ'_{cv}) can be determined for cohesive material using plasticity index values using the relationship provided in BS8002:2015 [15]. This suggests a φ'_{cv} of 30° (and c' of 0kPa) based on a plasticity index of 15% (based on the average PI from Atterberg Limit testing). This broadly agrees with the interpretation presented from the shear box testing.

Intact rock strength

Point Load Index

5.15.22 Axial and diametral point load ($I_{s(50)}$) tests (126 tests) were undertaken on the BDS and the results are presented in Appendix F (refer to figure F9.12). A total of 53 $I_{s(50)}$ results of zero are reported in the dataset with maximum values of 1MPa and an average $I_{s(50)}$ of 0.14MPa. There was no significant difference between the axial and diametral tests.

Unconfined compressive strength (laboratory testing)

5.15.23 Four unconfined compressive strength (UCS) tests were undertaken on siltstone samples of the BDS (refer to Appendix F, figure F9.13). The recorded UCS ranged from 2.7 to 18.5MPa with an average of 8MPa. The range corresponds to very weak to moderately weak strengths and corresponds to the logged strength of the rock.

5.15.24 No correlation with $I_{s(50)}$ could be established due to the range in UCS and limited $I_{s(50)}$ tests at the UCS test locations.

Rock mass strength

5.15.25 Rock mass parameters have been interpreted using the Hoek-Brown criterion [21]. The rock mass parameters for the intact material is as follows (for the purposes of design, parameters should be developed in a location specific basis):

- φ’ = 15°
- c’ = 150 kPa

5.15.26 This is based on the following input parameters:

- UCS = 8MPa
- GSI = 40 (rock structure is assumed to be blocky, disturbed (many intersecting joint sets) and the surface condition of the discontinuities as fair (smooth, moderately weathered and altered surfaces))
- Mi = 5 (siltstone)
- D = 0.7 (mechanical excavation)
- MR = 350 (siltstone)
- General condition applied - the BDS is unlikely to be disturbed by excavation works

Consolidation

5.15.27 One consolidation test was carried out on a sample of slightly sandy clayey silt from DSRC301 at 30.5m bgl (refer to Appendix F, figure F9.14). The sample was tested up to a pressure of 3200kPa. Recorded values of the coefficient of volume compressibility (m_v) vary over the pressure range applied from 0.28m^2/MN to 0.033m^2/MN but in general typically range from 0.07m^2/MN to 0.02m^2/MN. The typical range generally corresponds to m_v values associated with over consolidated to heavily over consolidated clays [17].

Permeability

5.15.28 The BDS was typically logged as a sandy clayey silt/clay (occasionally fissured) material with more competent beds of siltstone. Within the highly weathered zone, groundwater flow is mostly through fissures with a secondary component via the soil matrix. Within the competent bedrock, groundwater flow is via fractures within the rock mass.". Two variable head tests were completed in the soil variety of the BDS, indicating a K range of 3.2x10-6 and 1.1x10-5 m/s [2].

5.15.29 The results are discussed in further detail within the hydrogeological interpretation presented in Section 5.17.

5.16 Lias Group Mudstones

Description

5.16.1 Table 5-21 presents a summary of the logged description of the Lias Group. The table has been split into the following Lias locations:

- Below the escarpment
- Below the mass movement deposits

5.16.2 The upper surface of the Lias within the logs has been based on a colour change from the overlying mass movement deposits, a change from orange brown to grey (refer to Section 5.9). However, the distinction is not clear cut as the mass movement deposits have originated from the Lias and in areas could feasibly represent a weathered Lias profile.

Table 5-21 Lias Group description summary

Lias location	Typical description	Depth to upper surface (mbgl or mAOD)	Thickness (m)
Below escarpment (Ch 1+700 to Ch 2+100)	Extremely weak to very weak thinly laminated dark grey mudstone. Locally tending towards siltstone or locally disintegrated to a very stiff to friable clay. Frequent laminae of silt Encountered as a very stiff fissured dark grey silty clay tending to extremely weak mudstone (DSRC408)	39m bgl to 46.4 (186.1 to 194mAOD)	Not penetrated (>66m)
	No distinct limestone band (Marlstone Rock) encountered		
Below Landslip (Crickley Hill valley Ch 0+500 to Ch 1+700)	Below landslip upper surface of Lias encountered as: Stiff to very stiff thinly to thickly laminated dark grey slightly sandy silty clay (in areas locally tending towards an extremely weak mudstone). This has been termed the Lias Group (clay). Noted to be fissured in several locations with fissures sub horizontal to 70°, closely to medium		1.4 to 18m (average 5 to 6m)

Lias location	Typical description	Depth to upper surface (mbgl or mAOD)	Thickness (m)
	spaced, undulating and smooth to rough. Some green to orange red staining on fissures noted CP102 and CP204 encountered orange brown colouration for top 2 to 4m Absent in CP210, CP211, CP212, CP223, DSRC205, DSRC224 overlying		
	Extremely weak to weak thinly laminated dark grey mudstone. In DSRC224 from 32 to 35.5m, very stiff fissured thinly laminated dark grey clay with sub-horizontal very closely spaced planar smooth and locally polished	9 to 26m	Not penetrated (>61m)
	Following beds noted within the mudstone: • Medium strong to strong dark grey and grey limestone with either frequent to rare shell fossils/moulds or described as bioclastic. Possible Marlstone Rock Formation Not encountered in all boreholes • DSRC224, frequent limestone nodules and thin beds of limestone from 45 to 60m (approaching Marlstone Rock) • Sandstone 1.5m thick in CP223 (21.1m bgl, 158.65m OD)	142 to 174mAOD	0.15 to 1.6m (average 0.65m)

5.16.3 The surface geophysics has been used to help identify the Lias boundary underlying the Mass Movement Deposits as presented in Section 5.9. The top of the Lias is predicted to occur at around 15 to 20m below ground level. An exception to this is line 12 where a stepped profile in the Lias is predicted where the depth to Lias on the down slope extent of the line is around 28m below ground level. There is no borehole in this area to validate this interpretation.

5.16.4 The downhole geophysics are not conclusive in terms of identifying the top of the Lias when underlying the Mass Movement Deposits. For the holes where the Lias is below the Bridport sands (below the escarpment) the logged top of Lias can be observed as a drop on gamma associated with a distinct drop in long spaced density and provides good agreement with the logged upper surface.

Rock mass quality

5.16.5 The following summarises the rock mass quality for the Lias Group below the escarpment:

- Bedding (or fissures) are sub-horizontal to 20°, closely to medium spaced, planar to undulating and smooth to rough. Subvertical and randomly orientated incipient joints noted.

- Average fracture spacing varies from 90 to 650mm (refer to Appendix F, figure F10.01). From the top of the Lias Group to around 35m the average fracture spacing is around 150mm after which the average fracture spacing increases to around 250mm
- RQD ranges from 50 to 95% with values generally ranging from 70 to 90% (refer to Appendix F, figure F10.02)

5.16.6 The following summarises the rock mass quality for the Lias Group below the Mass Movement Deposits:

- Discontinuities are:
  - Predominantly sub horizontal to 30^{o}, closely to medium spaced, planar to undulating and smooth to rough, interpreted as bedding.
  - A joint set, 50^{o} to 80^{o} medium spaced planar and smooth (recorded as stepped in CP202 between 10 and 16m depth).
  - Occasional staining (red to grey) and silt infill recorded (staining of discontinuities, red brown to black penetrating 20mm to 60mm in CP211).
  - BGS logging of DSRC224 noted from:
    - 37.5 to 37.51m bgl a polished oblique fracture zone of rubbly angular mudstone fragments
    - Polished oblique fracture zone of rubbly angular broken mudstone from 37.5 to 37.51m
  - Increase in fracturing from 28m to 36m in DSRC107 and DSRC108 (based on down hole optical geophysics)
- Fracture spacing varies from 20 to 1330mm. A grouping of data with fracture spacings of 50 to 200mm can be observed from 10m to around 40m depth. Slightly higher fracture spacing with depth can be observed but there is a large scatter of data that is based on one borehole, DSRC224.
- RQDs range from 0 to 100% but show a reduced scatter with depth for the limited boreholes extended below 40m depth.

Marlstone Rock

5.16.7 Based on the Hutchinson [11] thicknesses for the Lias, and the base of the Inferior Oolite (as presented in Section 5.13) it is interpreted that the Marlstone Rock would outcrop at Ch 1+200 at around 152.5 to 137.5mOD. This is based on a structural contour assessment using the assumed thickness of the Upper Lias and a bedding dip of 2^{o} to the south east.

5.16.8 As stated in 5.14.6, the Marlstone Rock can be used as a marker bed and it is predicted that at around Ch 1+200 it may be present at around 137.5 to 152.5mOD. The BGS (Appendix C) state that it is a very-strong (hard) limestone below the basal belemnite-rich ‘Cephalopod Beds’ of the Whitby Mudstone Formation. Several boreholes encountered limestone beds within the Lias either as one bed or as a number of beds of varying elevation. Where the limestone beds have been described as containing frequent fossils then this has been assumed to represent the Marlstone Rock. The following observations are made from the logs:

- The Marlstone Rock was not identified in all boreholes (based on no limestone being logged).

- Towards the centre line of the scheme at around Ch 1+200, it was encountered at 152m AOD in CP105 and CP213. This may represent in-situ Marlstone Rock.
- Away from the centre line, within the Crickley Hill valley, the Marlstone Rock was recorded at varying levels that are generally higher than the predicted level based on the proposed outcrop in the valley based on Hutchinson [11] and the regional dip of the formation. This either suggests that this is not the Marlstone Rock or represents disturbed Marlstone Rock. This is discussed further in Section 7.4.
- The BGS and GEL have logged the Marlstone Rock in DSRC224 at 158.4mOD. If this is undisturbed then the predicted levels based on Hutchinson [11] would be higher than predicted. This would result in a predicted level of around 180m AOD towards the centre line of the scheme at Ch1+200.
- The deeper boreholes within the escarpment (DSRC301, DSRC109), drilled beyond the predicted depth (based on Hutchinson [11]) of the Marlstone Rock did not encounter the formation. However, in DSRC109 the optical televiewer may suggest a limestone band from 83.2 to 85.2mbgl (roughly 150m AOD) that agrees with the predicted level based on Hutchinson [11].

5.16.9 Based on the above, determination of the insitu location of the Marlstone Rock is inconclusive.

Engineering properties

Classification

5.16.10 Results of classification testing on samples of the Lias Group are presented below in Table 5-22 and the associated plots are presented in Appendix F (refer to figures F10.03 to F10.06).

Table 5-22 Classification testing summary – Lias Group

Property	Range	Average value	Observed trends
Bulk unit weight (kN/m^3)	19.5 to 23.2	21.5	Scatter of data within the top 20m below which testing is limited but shows in increase with depth Rock testing for unit weight fits within the range stated but the average unit weight is $22kN/m^3$.
Natural moisture content (%)	5 to 28%	15%	Generally, a limited scatter range (10 to 20%) but a reduction in moisture content with depth. Elevated values towards the upper surface in a few locations (moisture content range of 20 to 30%)
			Rock moisture content testing rages from 4 to 13% with an average of 11% and in general shows a reduction in depth
Liquid Limit (%)	35 to 60	50 (top 20m) reducing to 45 (below 20m)	65 Atterberg Limit tests within the clay from 1.5 to 23mbgl and 32 Atterberg Limit tests in rock (predominantly below 25m bgl) were conducted.

Property	Range	Average value	Observed trends
Plastic Limit (%)	20 to 25	22	General grouping of data (based on plasticity chart) between intermediate to high plasticity but there is a scatter of data down to low plasticity. Scatter of LL within the top 20m but an overall reduction with depth to around 50m after which an increase can be observed (based on one borehole) Within the top 30m PL around 25, below which slight reduction to around 20. Moisture contents lower than PL except for a few locations. All correspond to the stiff to very stiff consistency description Higher PI within the upper 20m with a slight reduction with depth
Plasticity Index (%)	15 to 32	27	

Note: Atterberg testing within the rock was conducted to try and differentiate between the different formations within the Lias Group. However, no differences in classification behaviour between Lias Group Formations is discernible from the testing

Particle Size Distribution

5.16.11 No particle size distribution testing was conducted within the Lias Group.

Strength

Standard Penetration Tests

5.16.12 The results of standard penetration tests within the Lias Group are presented in Appendix F (refer to figure F10.07 and F10.08). The N_{60} values given have mostly been extrapolated from the measured blow counts. The SPT N_{60} plot presents the SPT N_{60} values for the Lias Group below the MMDs (both clay and rock) and the Lias Group below the escarpment.

5.16.13 The following summarises the findings of the SPT N_{60} results:

- SPT N_{60} range from 11 to 230 within the Lias Group (clay) below the MMD with an average value of N 75. In general, the N_{60} values increase from around N_{60} 11 to N_{60} 150 at around 20m depth
- SPT N_{60} values in the Lias Group (rock) below the MMD have a scatter of results ranging from 71 to 1000 between 20 to 40m depth with an average value of N_{60} 280
- SPT N_{60} range from 186 to 1500 for the Lias Group below the escarpment with an average value of N_{60} 550. In general, the N values increase from around N_{60} 200 to N_{60} 800 between 40 and 100m depth

5.16.14 The test results highlight the difference in strength of the Lias Group depending on the overlying ground conditions.

5.16.15 For the Lias Group (clay) below the MMD, at around 20m depth a grouping of SPT N_{60} results are slightly lower than the overall trend of increasing values. On inspection of the logs there is no clear evidence to suggest why lower SPT N_{60} values have been recorded.

Undrained strength

5.16.16 Unconsolidated undrained triaxial tests on 4 samples from the Lias Group (clay) below the MMD recorded undrained shear strength, c_u, values of 110 to 160 kN/m^2 (see Appendix F, figure F10.09). This range corresponds with the logged stiff to very stiff consistency of the material.

5.16.17 One consolidated undrained triaxial test from the Lias Group (clay) below the MMD recorded an undrained shear strength of 255 kN/m^2. This is slightly higher than the unconsolidated undrained triaxial tests but still agrees with the logged very stiff consistency at the test depth.

5.16.18 Two hand vanes conducted on material retrieved from boreholes CP213 and CP215 within the Lias Group (clay) below the MMD both recorded an undrained shear strength of 95kN/m^2. This corresponds with the logged stiff consistency of the material.

5.16.19 For the Lias Group (clay) below the MMD, correlation of c_u with SPT N [14] indicates a c_u range of 55 to 750 kN/m^2 based on the SPT N_{60} range of 11 increasing to 150 and an f_1 coefficient of 5 based on a PI of 27 (refer to Appendix F, figure F10.10). The predicted increase in c_u with depth reflects the logged consistency of the material and the higher values are indicative of an extremely weak rock (as logged with depth).

5.16.20 The laboratory testing predicts c_u towards the lower bound correlated values with SPT N_{60}.

Drained strength

5.16.21 Three small reversed shear box tests were conducted on recompacted/remoulded samples of the Lias Group clay ranging in depth from 14 to 35m below ground level. The tests were conducted at normal stresses ranging from 150 to 600kN/m^2. The tests were conducted up to a displacement of 35mm and both a peak and residual angle of shearing resistance were reported. Classification testing conducted at the shear box test depths indicate moisture contents of 13 to 18% and plasticity indices of 17 to 25%.

5.16.22 The shear box test results are presented in Appendix F (refer to figure F10.11 and F10.12). The range in strength parameters based on the testing are as follows:

Table 5-23 Strength parameters for Lias Group determined from shear box testing

Strength (based on shear box test)	Effective angle of shearing resistance range (ϕ') (degrees)	Effective cohesion range (c') (kN/m^2)
Peak	22 to 28	0 to 10 (respectively)
Residual	10 to 22	0

5.16.23 One multi-stage and three single stage (set of three samples) consolidated undrained with pore water measurement triaxial tests were conducted on undisturbed samples obtained from DSRC107 at 12.6m depth and CP214 at 10.6m depth. Classification testing conducted at the triaxial test depths indicate moisture contents of 15 and 22% and plasticity indices of 23 and 26%.

5.16.24 The results of the triaxial testing are presented in Appendix F (refer to figure F10.13). The testing suggests the following strength parameter range:

- effective angle of shearing resistance of 32 to 33°
- effective cohesion (c') of 0 to 20kN/m^2

5.16.25 This is higher than the general magnitude of ϕ'_{peak} and c'_{peak} interpreted from the shear box testing. Based on the recompacted sample and the lower peak behaviour on shearing (based on the stress strain curves) it is likely that the shear box peak values are closer to the constant volume values. The triaxial data is likely to represent the true peak shear strength parameters.

5.16.26 Two residual strength by ring shear tests were conducted on samples obtained from CP204 at 6.5m depth and DSRC224 at 35.4m depth. Classification testing conducted close to the ring shear test depths indicate moisture contents of 4 and 25% and plasticity indices of 22 and 24%. Both samples were described as a silty clay and the lower moisture content test was from the deeper sample.

5.16.27 The results of the ring shear testing are presented in Appendix F (refer to figure F10.14). The testing suggests the following strength parameter range:

- effective angle of shearing resistance of 9 to 19°
- effective cohesion (c') of 0kN/m^2

5.16.28 The strength parameters from the ring shear testing are in broad agreement with the residual strength parameter range determined in the shear box testing.

5.16.29 To allow for a comparison of the laboratory based strength testing, constant volume angle of shearing resistance (φ'_{cv}) can be determined for cohesive material using plasticity index values provided in BS8002:2015 [15]. This suggests a φ'_{cv} of 24° based on a plasticity index of 24% (based on the average PI from the effective stress test samples). This agrees with the interpretation presented on 5.12.32 and the shear box testing.

5.16.30 The residual strength parameter range presented can also be compared against PI as presented by Lupini et al [16]. Based on a plasticity index of 24% (as presented in 5.12.36) a residual shear strength in the order of 20° could be anticipated based on Lupini et al [16] which is towards the upper end of the range recorded by the testing.

Intact rock strength

5.16.31 Point load index testing with depth for the Lias Group is presented in Appendix F (refer to figure F10.15). Two hundred and seventeen tests were conducted that recorded point load indices (Is_{50}) of 0 to 3.1MPa with an average of 0.23MPa. In general, the data set ranges from 0.1 to 0.4MPa with 18 tests in excess of 0.5MPa that are predominantly associated with limestone layers within the Lias Group. Four of the higher values are associated with mudstone from the Lias Group, from DSRC301 at depths ranging between 50m and 95m. There is no differentiation between the point load index tests results from boreholes below the escarpment to boreholes below the MMDs.

5.16.32 Unconfined compressive strength (UCS) testing with depth for the Lias Group is presented in Appendix F (refer to figure F10.16). Fifteen UCS tests were conducted at depths ranging from 9.5 to 103m bgl with recorded values ranging from 0.17 to 7.8MPa with an average of 1.8MPa. The testing suggests a UCS range of 0.2 to 1.5MPa to depths of 20m bgl and a UCS range of 2 to 4MPa at depths greater than 20m bgl..

5.16.33 The UCS testing is in agreement with the logged descriptions of extremely weak to weak (Table 25 from BS5930:2015, [18]).

Stiffness

5.16.34 Stiffness parameters for the Lias Group clay are presented due to the proposed embankments along Crickley Hill. No stiffness parameters for the rock are presented at this stage.

5.16.35 Undrained and drained Young's Modulus (E_u and E') for the Lias Group clay has been based on the correlation for cohesive materials presented in CIRIA 143 [14].

- E_u = 1.1 x N_{60} (MPa)
- E' = 0.9 x N_{60} (MPa)

5.16.36 Based on the general SPT N_{60} increase with depth (N_{60} 11 to N_{60} 150 at 20m depth) presented in 5.16.13, the following typical E_u and E' ranges would be anticipated for the Lias Group clay:

- E_u = 12MPa increasing to 160MPa at 20m depth
- E' = 10MPa increasing to 130MPa at 20m depth

Consolidation

5.16.37 One consolidation test was carried out on a sample of silty clay from DSRC301 at 41m bgl (refer to Appendix F, figure F10.17). The sample was tested up to a pressure of 3200kPa. Recorded values of the coefficient of volume compressibility (m_v) vary over the pressure range applied from 0.37m^2/MN to 0.013m^2/MN but in general typically range from 0.1m^2/MN to 0.01m^2/MN. The typical range generally corresponds to m_v values associated with over consolidated to heavily over consolidated clays [17].

5.17 Summary of hydrogeology

General

5.17.1 A total of 60 groundwater monitoring installations were constructed during the Phase 1 and Phase 2A ground investigations. Water level loggers are installed within 18 locations and manual dip measurements are taken on a monthly basis. Barometric loggers were installed within the headworks of DSRC 408, CP 223 and DSRC 220.

5.17.2 Monitoring of the Phase 1 locations commenced in February 2019 to collect long term groundwater monitoring data during the route selection process. Phase 2A locations progressively from May 2019, targeting the selected route option for the scheme. Monitoring of these locations will continue for one year following the completion of the Phase 2A works in October 2020. Results of monitoring following October 2020 will be provided to the Environment Agency (EA) for information purposes.

5.17.3 The scheme is underlain by three aquifers and two aquitards. The aquifers include the superficial deposits, the limestones of the Great Oolite Group and the Inferior Oolite Group. For the purposes of the hydrogeological conceptual models the superficial deposit aquifers include the Cheltenham Sand and Gravel formation, alluvium, mass movement deposits and head deposits. The Fuller's Earth Formation and Lias Group mudstones are low permeability strata that form barriers to flow resulting in locally perched groundwater in the overlying aquifers. These barriers influence the groundwater flow direction and result in ponding where dips or low points in the bedding are present. A summary of the hydrogeological units within the project area is presented in Table 5-24. Further detailed descriptions of the hydrogeological conceptual model are presented in ES Appendix 13.7, Hydrogeological Impact Assessment (Document Reference 6.4).

Table 5-24 Summary of hydrogeological units

Chainage	Group	Formation	EA aquifer designation	Description
0+000 to 0+500	-	Cheltenham Sand and Gravel	Secondary A aquifer	• High permeability minor aquifer • Susceptible to groundwater flooding
0+500 to 1+750 and 3+000		Superficial deposits (alluvium, mass movement deposits and head deposits)	Alluvium – Secondary A aquifer (not identified refer to Section 5.7) Mass movement deposits/head deposits – no aquifer designation	• Minor aquifer • Mostly low permeability, cohesive deposits with non-cohesive lenses. • Supports springs at Crickley Hill and valleys of the River Churn and River Frome • Some springs are tufa forming
3+000 to 5+789	Great Oolite Group	White Limestone Formation Hampen Formation	Principal aquifer	• Fractured limestone, high transmissivity and low storage • Deep unsaturated zone. • Supports springs over the Fuller's Earth Formation • Seasonal groundwater levels • Largely dry over summer south of the Stockwell fault
		Fuller's Earth Formation	Unproductive aquifer	• Low permeability aquitard • Includes the Througham Member (uppermost member) comprising interbedded limestone, mudstone and siltstone creating anisotropic K, limiting vertical groundwater flow. Seasonal groundwater levels. Supports springs over the Fuller's Earth Formation
1+750 to 3+500	Inferior Oolite Group	Salperton Limestone Aston Limestone Birdlip Limestone	Principal aquifer	• Fractured limestone aquifer with 'gulls' associated with cambering processes at the edge of the Cotswold escarpment and enhanced dissolution features

Chainage	Group	Formation	EA aquifer designation	Description
				• Iron stained voids more prevalent towards the base of the aquifer • High transmissivity and low storage. • Deep unsaturated zone • Supports springs at the Shab Hill Barn fault • Support springs in the underlying Bridport Sand Formation (e.g. spring S01) • Seasonal groundwater levels • Wide areas are dry over summer
0+000 to 1+750	Lias Group	Bridport Sand Formation	Principal aquifer (see Appendix 13.7 for details)	• Minor aquifer hydraulically connected to overlying Inferior Oolite Group • Seasonal groundwater levels • Voids present in fracture zones, particularly near the Cotswold escarpment, which support springs e.g. spring S01
		Whitby Mudstone Formation (WMF)		• Low permeability aquitard • Fissured clays in weathered zones • Potential to form a spring line with overlying Inferior Oolite Group and Bridport Sand
		Marlstone Rock Formation (within the WMF)		• Minor aquifer • Fracture dominated flow
		Dyrham Formation		• Low permeability aquitard
		Charmouth Mudstone Formation	Secondary aquifer (undifferentiated)	

5.17.4 Rainfall data for the Ebsworth monitoring station (approximately 5.4km south-west of the scheme) from 2018 to 2020 is presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4). Between 2009 and 2019 the average annual rainfall was 868 mm, where October to January are typically wetter months with rainfall up to 109 mm/month. Drier conditions were recorded between February and September when the minimum monthly rainfall recorded was 44 mm.

5.17.5 Over the groundwater monitoring period, below average rainfall was recorded from February 2018 to May 2019. During this period effective recharge rates and groundwater levels are likely to have been lower than average. From June 2019, the monthly rainfall rates were above average and as a result effective recharge and groundwater levels are likely to have been higher than average over this period. Further details on rainfall and the impact upon groundwater recharge are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

Hydrogeological investigations

5.17.6 Hydrogeological investigations undertaken as part of the A417 project include:

- groundwater level monitoring at targeted hydrogeological units
- testing of aquifer units by packer test and variable head tests
- hydrogeology specific down the hole geophysics, including impeller and temperature measurements

<u>Superficial aquifer - mass movement deposits</u>

5.17.7 A total of 16 groundwater monitoring locations have been installed within mass movement deposits and monitoring has progressively commenced since May 2019. The distribution of monitoring locations includes:

- 4 between Ch 0+500 and Ch 1+000 in the lower slopes of Crickley Hill
- 9 between Ch 1+000 and Ch 1+400 in the mid slopes of Crickley Hill
- 2 between Ch 1+400 and Ch 1+700 in the upper slopes of Crickley Hill

5.17.8 The locations of groundwater monitoring locations are presented in Figure 13.9 of the ES. Detailed discussion and hydrographs for each monitoring installation are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

5.17.9 Groundwater levels are relatively shallow near the tributary of Norman's Brook where the average levels recorded were between 0.4mbgl and 4.0mbgl. Further away from the tributary of Norman's Brook and further up the escarpment, the groundwater levels were recorded on average between 5.6mbgl and 8.4mbgl.

5.17.10 A seasonal response was observed in most monitoring locations where the observed range in groundwater levels were between 0.6m and 4.0m. The aquifer is typically highly responsive to direct recharge, particularly during winter months when the antecedent conditions are wetting.

5.17.11 The complex and predominately cohesive nature of the Mass Movement Deposits (MMD) results in some areas of the aquifer being less responsive to direct recharge. Locally confined sand and gravel units appear to be present throughout the MMD, resulting locally isolated pockets of groundwater. As a result, groundwater occurrence and the nature of groundwater regimes are very localised and complex on the escarpment.

<u>Great Oolite Group limestone aquifer</u>

5.17.12 A total of seven groundwater monitoring locations have been installed within the Great Oolite Group limestones and monitoring has progressively commenced since October 2019. The distribution of monitoring locations includes:

- 3 between Ch 3+000 and Ch 3+500 at Shab Hill Junction
- 3 between Ch 3+500 and Ch 5+000 between Shab Hill junction and Cowley junction
- 1 near the Bushley Muzzard SSSI

5.17.13 The groundwater monitoring locations are presented in Figure 13.9 of the ES. Detailed discussion and hydrographs for each monitoring installation are presented in the ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

5.17.14 At Shab Hill junction there is a deep unsaturated zone, between 12.7mbgl and 39.0mbgl, within the Great Oolite Group limestones. Over summer months large areas of the aquifer are dry and seasonal variations in groundwater levels are minimal (<0.5m). The aquifer shows little response to rainfall; however, this may be due to manual dips occurring on a monthly basis.

5.17.15 From Shab Hill junction to Cowley junction, the monitoring installations have been installed within the interbedded limestones and mudstones that form the transition zone between the Great Oolite Group Limestones and underlying Fuller's Earth Formation. The monitoring response zones are mostly within limestone beds, which are the dominant flow paths for groundwater. For this reason, the monitoring locations have been classified as being in the Great Oolite limestone aquifer. North of the Stockwell fault, recorded groundwater levels ranged between 0.6mbgl and 8.9mbgl, with groundwater levels highly responsive to direct recharge over the wetter winter months. South of the Stockwell fault at DSRC 401, groundwater levels were also seasonal, however there was a limited response to rainfall indicating the location receives indirect recharge. During summer months the aquifer was unresponsive to rainfall events and the aquifer was dry on the southern side of the Stockwell fault.

5.17.16 Downhole geophysics confirms the thickly interbedded nature of the Great Oolite Group and relatively high clay content. The geophysics also indicates that the aquifer has relatively few instances of secondary permeability (rock fractures) encountered and no tertiary permeability (solutionally enhanced fractures, such as karst).

5.17.17 Near Bushley Muzzard, monitoring within shallow, interbedded limestones and mudstones showed a seasonal response in groundwater levels up to 1.5mbgl. The location is responsive to direct recharge over winter months but is unsaturated and non-responsive to rainfall over summer months.

Fuller's Earth Formation aquitard

5.17.18 A total of three groundwater monitoring installations have been installed within the Fuller's Earth Formation and monitoring has progressively commenced since February 2019. The distribution of monitoring locations includes:

- 2 between Ch 3+500 and Ch 5+000 between Shab Hill junction and Cowley junction
- 1 at Ermin Way, west of the Bushley Muzzard SSSI

5.17.19 The locations of groundwater monitoring locations presented in Figure 13.9 of the ES. Detailed discussion and hydrographs for each monitoring installation are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

5.17.20 Between Ch 3+500 to Ch 4+475 the monitoring locations are within the Fuller's Earth Formation transition zone, mostly comprising mudstones with occasional limestone beds. Groundwater levels were recorded between 1.3mbgl and 5.4mbgl. The formation showed a variable response to rainfall events where DSRC 220 was only responsive to larger rainfall events over the winter months. Otherwise there was no recorded responsiveness to rainfall events. A seasonal variation of up to 2.4m was observed in the monitoring locations.

5.17.21 Downhole optical and natural gamma geophysics confirms the thinly interbedded nature of the Fuller's Earth Formation with high clay content. The geophysics also supports the view that the formation is likely to have relatively limited secondary permeability, with any fractures present typically infilled with clay.

5.17.22 At Ermin Way, OH 416 is installed into the Fuller's Earth Formation weathered zone where the seasonal range of groundwater levels was measured between 1.5mbgl and 3.6mbgl. The location responded rapidly to rainfall events, however fluctuation from individual events was small.

<u>Inferior Oolite Group aquifer</u>

5.17.23 A total of 22 groundwater monitoring installations are installed within the Inferior Oolite Group and monitoring has progressively commenced since February 2019. The distribution of monitoring locations includes:

- 12 between Ch 1+700 and Ch 2+000 at Air Balloon
- 2 near Barrow Wake
- 1 near the proposed B4070
- 5 between Ch 3+000 and Ch 3+500 at Shab Hill Junction
- 2 between Ch 3+500 and Ch 4+575 between Shab Hill junction and Cowley junction

5.17.24 The locations of groundwater monitoring locations presented in Figure 13.9 of the ES. Detailed discussion and hydrographs for each monitoring installation are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

5.17.25 A deep unsaturated zone (>19.3mbgl) is present within the Inferior Oolite Group at Air Balloon and the aquifer shows distinct seasonal differences. During summer months, wide areas of the aquifer are dry and water levels are only recorded in monitoring locations east of the Shab Hill fault where local undulations in the top of the Lias Group allows groundwater to pool. During winter months, groundwater has been typically recorded between 2m and 4m above the base of the aquifer (208.1mAOD and 212.3mAOD) and flashy responses were recorded either side of the Shab Hill fault.

5.17.26 Monitoring at Barrow Wake similarly showed a deep unsaturated zone and flashy groundwater level responses over the winter period following rainfall events. Groundwater levels were recorded up to 5.4m above the base of the aquifer, corresponding to 55mbgl. Over summer months the aquifer is dry in this area.

5.17.27 At Shab Hill junction the Inferior Oolite Group is overlain by the Great Oolite Group. Monitoring indicates there is a deep unsaturated zone within the Inferior Oolite Group where groundwater levels were recorded up to 10.7m above the aquifer base (46.6mbgl). Groundwater levels are seasonal, however little to no response from rainfall was recorded indicating that the aquifer is indirectly recharged in this area.

5.17.28 Downhole optical and natural gamma geophysics confirms the thickly interbedded nature of the Inferior Oolite Group and typical absence of clay infill to fractures. The geophysics also indicates that the aquifer locally has significant secondary and tertiary permeability.

5.17.29 Between Shab Hill junction and Cowley junction the Inferior Oolite Group is overlain by the Great Oolite Group. Over the summer months large areas of the

Inferior Oolite Group aquifer are dry, whilst over the winter months groundwater levels were recorded near the base of the aquifer (68mbgl). The aquifer in this area is not responsive to rainfall event indicating recharge is indirect.

Bridport Sand Formation minor aquifer

5.17.30 A total of two groundwater monitoring installations are installed within the Bridport Sand Formation and monitoring has progressively commenced since January 2019. The distribution of monitoring locations includes:

- one at Air Balloon
- one at Barrow Wake

5.17.31 The locations of groundwater monitoring locations presented in Figure 13.9 of the ES. Detailed discussion and hydrographs for each monitoring installation are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

5.17.32 Between CH1+700 and CH2+250 the Bridport Sand Formation is overlain by the Inferior Oolite Group. A seasonal response was recorded and groundwater levels were not responsive to rainfall events. The Bridport Sand Formation likely receives recharge from the overlying Inferior Oolite Group as groundwater levels are similar in both aquifers, up to 21.3mbgl (211.3mAOD).

5.17.33 At Barrow Wake the Bridport Sand Formation is overlain by the Inferior Oolite Group and also showed a similar seasonal response compared to Air Balloon. The deep unsaturated zone (up to 35.6mbgl) is responsive to rainfall events indicating a strong hydraulic connection to the overlying Inferior Oolite Group.

5.17.34 Downhole optical and calliper logging has identified in borehole DSRC 301 (located at the Cotswold escarpment edge) a void has developed, which is extends through the Bridport Sand Formation and terminating at the top of the underlying Whitby Mudstone Formation. It is possible the void initially developed in the overlying Inferior Oolite Group and groundwater flow has further developed the voids so there is local continuity with the underlying Bridport Sand Formation.

Lias Group mudstone aquitard

5.17.35 A total of eight groundwater monitoring installations are installed within the Lias Group mudstones and monitoring has progressively commenced since May 2019. The distribution of monitoring locations includes:

- 6 between Ch 1+000 and Ch 1+400 in the mid-slopes of Crickley Hill
- 1 at Air Balloon
- 1 in the upper slopes of Crickley Hill

5.17.36 The locations of groundwater monitoring locations presented in Figure 13.9 of the ES. Detailed discussion and hydrographs for each monitoring installation are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

5.17.37 At Crickley Hill the Lias Group is overlain by clay dominated mass movement deposits. Groundwater was typically between 10.1mbgl and 19.6mbgl, with shallower groundwater encountered near the tributary of Norman’s Brook. A seasonal response in groundwater levels was recorded, but little responsiveness to rainfall. Monitoring within mudstones showed a seasonal variation (up to 1.8m) compared to monitoring within the weathered mudstones (up to 2.7m), demonstrating the low permeability of the mudstones.

5.17.38 Downhole geophysics confirms the clay dominated nature of the Lias Group. The geophysics also indicates that the group has relatively few instances of secondary permeability but those present are often infilled with clay.

5.17.39 At Air Balloon the Lias Group is overlain by the Inferior Oolite Group. Monitoring at DSRCOH 304 commenced in March 2020, but the results so far indicate groundwater levels are likely to be seasonal and little response to rainfall has been observed.

Hydrogeological conceptual model

Overview

5.17.40 There are two aquitards and three aquifers included with the hydrogeological conceptual model for the scheme. The aquifers include the superficial deposits (head deposits, mass movement deposits and the Cheltenham Sand and Gravel), the limestones of the Great Oolite Group and the Inferior Oolite Group. The Fuller's Earth Formation and Lias Group mudstones are low permeability strata that form barriers to flow causing perched groundwater in overlying aquifers. These barriers can influence flow direction but also create ponding where structural controls are present. Detailed descriptions of the hydrogeological units included in the conceptual model are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4).

5.17.41 A summary of the minimum and maximum groundwater levels likely to be encountered along the mainline are presented in Table 5-26. The minimum groundwater levels represent the lowest seasonal levels recorded, which generally represent groundwater levels in September. The maximum groundwater levels presented are peak levels recorded during the winter. Five monitoring locations (out of 22) in the Inferior Oolite Ground include flashy hydrographs associated with secondary/tertiary flow and these are not included in the peak groundwater level contouring.

5.17.42 An excerpt of the proposed hydraulic parameters presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4) is presented in Table 5-25.

Table 5-25 Proposed hydraulic parameters

Unit	Description	K, minimum (m/s)	K, maximum (m/s)
Mass movement deposits and dead deposits	Clay, sand/gravel bands	1.0×10^{-8}	1.0×10^{-4}
Cheltenham Sand and Gravel	Sand and gravel	1.0×10^{-4}	1.0×10^{-2}
Great Oolite Group	Fractured limestone	2.0×10^{-6}	2.0×10^{-4}
	Fuller's Earth Formation	2.0×10^{-8}	2.0×10^{-7}
Inferior Oolite Group	Fractured limestone	1.0×10^{-6}	1.0×10^{-4}
	Massive limestone	3.0×10^{-11}	3.0×10^{-9}
Lias Group	Bridport Sand Formation	1.0×10^{-7}	1.0×10^{-5}
	Mudstone	1.0×10^{-11}	1.0×10^{-7}

Superficial deposits

5.17.43 The superficial deposits comprise mass movement deposits (MMD) which form areas in the lower ground on the western and eastern approaches to the scheme. The head deposits are dominantly clay but include sand and gravel lenses and larger blocks of Inferior Oolite limestone from the upslope escarpment, which are locally recharged and often associated with springs and seepages. A number of the springs and seepages are tufa forming.

5.17.44 Within the Crickley Hill area, groundwater flow paths in the mass movement deposits typically follow the topographical slopes and generally flow towards surface water features such as the tributary of Norman's Brook and the unnamed tributaries that flow into this watercourse. Within the Churn and Frome valleys, groundwater flows within head deposits are also likely to follow topographical slopes and drain towards the river headwaters.

5.17.45 The mass movement deposits at Crickley Hill are directly recharged and generally are responsive to rainfall events. Over winter months some locations show a rapid response to rainfall events and little to no response over summer months.

5.17.46 Head deposits in the Churn and Frome valleys are directly recharged and indirectly recharged from springs emerging from the Great Oolite Group.

Great Oolite Group limestone aquifer

5.17.47 The Great Oolite Group is crossed by the scheme from Shab Hill junction southwards. In this area the groundwater levels are strongly controlled by faulting with groundwater being isolated to fault blocks and the faults themselves allowing leakage to the Inferior Oolite Group underlying the Fuller's Earth Formation.

5.17.48 The seasonal minimum groundwater levels within the Great Oolite Group are presented in ES Figure 13.13 Groundwater contours – Great Oolite Group, minimum levels (Document Reference 6.3). During the summer months groundwater levels were only recorded on the northern side of the Stockwell fault. On the southern side of the Stockwell fault the aquifer is dry. Summer groundwater levels on the northern side of the fault indicate a southward groundwater flow to the fault.

5.17.49 The seasonal maximum levels presented on ES Figure 13.14 Groundwater contours – Great Oolite Group, maximum levels (Document Reference 6.3) show groundwater flow is largely to the south and south-west and groundwater levels were recorded within the Great Oolite Group underlying Cowley junction as well.

5.17.50 The Great Oolite Group is directly recharged and is highly responsive to rainfall over winter months. Over summer months, the aquifer shows little to no response to rainfall events. There may also be a component of indirect recharge in the Great Oolite Group limestones between Shab Hill junction and Cowley junction, where vertical leakage and interflows may also recharge the limestone beds.

Inferior Oolite Group aquifer

5.17.51 The seasonal minimum groundwater levels within the Inferior Oolite Group are presented in ES Figure 13.11 Groundwater contours – Inferior Oolite Group, seasonal minimum levels (Document Reference 6.3). The minimum groundwater levels were recorded over summer months and these show that wide areas of the aquifer were fully drained over extensive periods of time. Summer groundwater levels were only recorded at Air Balloon, east of the Shab Hill fault, where the top of the Lias Group is down faulted into a graben structure. In this area the Inferior Oolite Group is lower in elevation and bound by the Lias Group, which causes groundwater levels in the Inferior Oolite Group to pond.

5.17.52 The seasonal maximum groundwater levels of the Inferior Oolite Group area presented in ES Figure 13.12 Groundwater contours – Inferior Oolite Group, seasonal maximum levels (Document Reference 6.3). The maximum groundwater levels were recorded over winter months. Within the Air Balloon area groundwater flow is towards the existing A417 cutting. Between the Shab Hill junction and Cowley junction, south of the Shab Hill Barn fault groundwater flow is towards the south east.

5.17.53 From the monitoring results it is clear that the Air Balloon area is on the western side of the groundwater divide and the Shab Hill junction to Cowley junction area is on the eastern side of the groundwater divide. The monitoring data indicate that the groundwater divide is likely to vary seasonally.

5.17.54 The Inferior Oolite Group is directly recharged by rainfall where at ground surface and indirectly via faults which drain the overlying Great Oolite Group limestones. Groundwater flow near the crest of the Cotswold escarpment is likely to be ‘flashy’ as flows through the voids towards the base of the group are likely to be rapid and short lived.

Table 5-26 Summary of groundwater levels along scheme mainline

Earthworks zone	Chainage (m)	Hydrogeological units	Maximum GWL[1]	Minimum GWL[1]	Groundwater regime characteristics
1	0+000 – 0+450	Superficial deposits (Cheltenham Sand and Gravel)	Ground surface	-	• Mapped potential for groundwater flooding to occur at surface • Groundwater flow towards the west
2	0+450 – 1+700	Mass movement deposits Lias Group mudstones	Ground surface	5.0mbgl [2]	• Seasonal variations between 0.6m and 4.0m and responsive to rainfall inputs • Groundwater flow follows topographical slope, towards the tributary of Norman's Brook
3	1+700 – 3+080	Inferior Oolite Group Bridport Sand Formation Lias Group mudstones	212.0mAOD	Dry west of Shab Hill fault and 209mAOD east of Shab Hill fault	• High degree of hydraulic connectivity within Inferior Oolite Group across Shab Hill fault • Inferior Oolite Group and Bridport Sand Formation hydraulically connected • Groundwater flow towards existing A417 cutting. • Springs occur at Shab Hill Barn fault
4	3+080 – 3+520	Great Oolite Group limestone Fuller's Earth Formation	269.4mAOD	269.0mAOD	• Piezometric surface in Great Oolite Group limestone influenced by dry valley, which reduced groundwater level to 215.9mAOD during winter • Shab Hill fault, Shab Hill Barn fault and Churn Valley fault provide vertical flow paths for groundwater to drain from the Great Oolite Group limestone to underlying Inferior Oolite Group
		Inferior Oolite Group	200.0mAOD	196.0mAOD	
5	NA	Great Oolite Group limestones Fuller's Earth Formation	269.4mAOD	269.0mAOD	• Located below eastern half of the B4070 realignment • Shab Hill Barn fault provides a vertical flow path for groundwater to drain from Great Oolite Group limestone to the underlying Inferior Oolite Group
		Inferior Oolite Group Bridport Sand Formation	235.0mAOD	228.9mAOD	At surface below western half of the B4070 realignment

Earthworks zone	Chainage (m)	Hydrogeological units	Maximum GWL[1]	Minimum GWL[1]	Groundwater regime characteristics
6	3+520 – 4+500	Great Oolite Group limestone Fuller's Earth Formation	281.0mAOD	271.5mAOD	• Groundwater flow towards south
		Inferior Oolite Group	206.0mAOD	Dry	• Groundwater flow towards the south-east
7	4+500 – 4+610	Great Oolite Group limestone Fuller's Earth Formation	271.0mAOD	270mAOD	• Groundwater flow towards south • Stockwell fault provides a vertical flow path for groundwater to drain from Great Oolite Group limestone to the underlying Inferior Oolite Group
		Inferior Oolite Group	201.0mAOD	Dry	• Groundwater flow towards the south-east
8	4+610 – 4+740	Great Oolite Group limestone Fuller's Earth Formation	270.5mAOD	Dry south of Stockwell fault	• Groundwater flow towards south-west
		Inferior Oolite Group	200.0mAOD	Dry	• Groundwater flow towards the south-east
9	4+740 – 4+800	Great Oolite Group limestone Fuller's Earth Formation	270.0mAOD	Dry	• Groundwater flow towards south-west
		Inferior Oolite Group	199.5mAOD	Dry	• Groundwater flow towards the south-east
10	4+800 – 5+300	Great Oolite Group limestone Fuller's Earth Formation	267.0mAOD	Dry	• Groundwater flow towards south-west
		Inferior Oolite Group	199.0mAOD	Dry	• Groundwater flow towards the south-east
11	5+300 – 5+480	Great Oolite Group limestone Fuller's Earth Formation	262.0mAOD	Dry	• Groundwater flow towards south-west
		Inferior Oolite Group	198.0mAOD	Dry	• Groundwater flow towards the south-east
12	NA	Great Oolite Group limestone Fuller's Earth Formation	265.0mAOD	Dry	• Groundwater flow towards south-west
		Inferior Oolite Group	198.0mAOD	Dry	• Groundwater flow towards the south-east

Note: 1. Based on groundwater monitoring completed up until October 2020
2. Depth below ground level presented due to large change in elevation over this zone

Hydrogeological features

Springs

5.17.55 Groundwater springs are ubiquitous within the Cotswolds escarpment region (ES Figure 13.5 Hydrogeological study area and features (Document Reference 6.3)). Most springs in the study area are associated with the mass movement and head deposits but there are also several limestone springs. Many of the springs (both head and limestone) are seasonal features that dry out in response to lower groundwater levels within the respective source aquifer.

5.17.56 Mapped limestone springs in the region correlate to bedrock formations and boundaries or structural features including:

- The Great Oolite Group at the boundary with the Fuller's Earth Formation and overlying Limestone Formations.
- The Inferior Oolite Group (in spatially limited connection with Bridport Sand) at the boundary with the underlying Lias Group mudstone.
- The Shab Hill Barn fault.

5.17.57 Springs (perennial and seasonal) also emerge from the Mass Movement Deposits along the Cotswold escarpment where preferential flow paths have developed through more permeable zones of the mixed material. Some springs located at the tributary of Norman's Brook, the Fly Up bike park and the River Frome headwaters are also tufa forming. Description of the tufa forming processes are presented in ES Appendix 13.7 Hydrogeological Impact Assessment (Document Reference 6.4). The identified tufa deposits have been surveyed by a specialist ecologist with respect to tufa habitats. The report is presented in ES Appendix 8.24 Assessment of tufaceous vegetation (Document Reference 6.4).

5.17.58 Springs at Bushley Muzzard SSSI and within the surrounding valley form the headwater of the River Frome. Based on the geology and groundwater levels, those springs that feed Bushley Muzzard SSSI are in a separate groundwater sub-catchment to the scheme.

Dry Valley

5.17.59 Dry valleys are located at Shab Hill junction and Barrow Wake SSSI (ES Figure 13.5 Hydrogeological study area and features (Document Reference 6.3)). Dry valleys in limestone terrains are glaciofluvial karst features within which seasonal streams may flow episodically, e.g. following high rainfall events [24]. Seepage has been observed within the Shab Hill junction dry valley and is presented on ES Figure 13.5 Hydrogeological study area and features (Document Reference 6.3).

5.18 Ground aggressivity to buried concrete

Introduction

5.18.1 This section provides an assessment of the aggressivity of the ground to buried concrete, in accordance with BRE Special Digest 1:2005 Concrete in aggressive ground (BRE SD1) [25]. There are numerous structures and foundations along the proposed Scheme and an assessment for each individual structure would need to be carried out at detailed design.

5.18.2 This section provides a summary of the relevant chemical laboratory tests undertaken in the ground investigation, the results for each strata and the characteristic values determined in accordance with BRE SD1. The Design Sulfate (DS) Class and the Aggressive Chemical Environment for Concrete (ACEC) Class is provided for each strata.

Summary of the relevant laboratory chemical tests undertaken, the results and characteristic values

5.18.3 A summary of the relevant tests that meet the requirements of BRE SD1 are provided in the following sections. These include the following:

- Soluble sulfate in 2:1 water/soil extract (WS)
- Groundwater soluble sulfate (GWS)
- Total sulfate content (AS)
- Total sulphur (TS)
- pH

5.18.4 The results of the above testing per strata are summarised in Appendix G.

Soluble sulfate in 2:1 water/soil extract (WS)

5.18.5 A total of 48 soluble sulfate in 2:1 water / soil extract (WS) tests were undertaken on soil samples from the ground investigation. The results are summarised in Appendix G.

5.18.6 The characteristic values for each geological unit have been determined in accordance with BRE SD1. If only a small number of samples were tested, the highest measured sulfate concentration (mg/l SO4) was taken as the characteristic value. In a data set where there are 5 to 9 results available, the mean of the highest two results was taken as the characteristic value. In a data set where there are 10 or more results, the mean of the highest 20% was taken as the characteristic value.

5.18.7 A summary of the number of soluble sulfate in 2:1 water / soil extract tests carried out and the characteristic values for each stratum is provided below.

Table 5-27 Summary of the number of soluble sulfate in 2:1 water / soil extract (WS) tests carried out for each stratum and the characteristic values

Strata	No of tests	WS characteristic value (mg/l)
Cheltenham Sand and Gravel	0	n/a
Mass movement deposits (Shab Hill)	0	n/a
Mass movement deposits (Crickley Hill)	12	1400
Head Deposits	2	<10
Great Oolite Group – Limestone	4	<10
Great Oolite Group – Fuller's Earth Formation	8	685
Inferior Oolite Group	10	450
Lias Group – Bridport Sand Formation	4	840
Lias Group	8	770

Groundwater soluble sulfate (GWS)

5.18.8 A total of 65 groundwater soluble sulfate (GWS) tests were undertaken during the Phase 1 and Phase 2A ground investigations. The results are summarised in Appendix G.

5.18.9 The characteristic values have been determined in accordance with BRE SD1. The highest determined sulfate concentration was taken as the characteristic value. The maximum value recorded was 392mg/l.

Total potential sulfate (TPS)

5.18.10 The total sulfate content (AS) and total sulphur (TS) tests were carried out on 48 soil samples from the Phase 1 and Phase 2A ground investigations. From these results, the total potential sulfate (TPS) and the amount of oxidisable sulphides (OS) has been calculated using the following equations, as outlined in BRE SD1:

$$TPS = 3 \times TS \text{ and } OS = TPS - AS$$

5.18.11 The results are provided in Table 5-28. BRE SD1 states that if the amount of oxidisable sulfides (OS) is greater than 0.3% in a significant number of samples, then pyrite is probably present. The total number of tests and number of samples where OS > 0.3% for each stratum is summarised below.

Table 5-28 Summary of the number of total sulfate content (AS) and total sulphur (TS) tests carried out for each stratum and the number of tests where the oxidisable sulphides (OS) is >0.3%

Strata	No. of AS & TS tests	No. of tests where OS > 0.3%	% of tests where OS > 0.3%
Cheltenham Sand and Gravel	0	n/a	n/a
Mass movement deposits (Shab Hill)	0	n/a	n/a
Mass movement deposits (Crickley Hill)	12	7	58%
Head Deposits	2	0	0%
Great Oolite Group – Limestone	4	0	0%
Great Oolite Group – Fuller's Earth Formation	8	7	87.5%
Inferior Oolite Group	10	3	30%
Lias Group – Bridport Sand Formation	4	4	100%
Lias Group	8	8	100%

5.18.12 Based on the results summarised above, pyrite is likely to be present in the Lias Group, Lias Group – Bridport Sand Formation and Great Oolite Group – FEF. It is also likely to be present in the MMD in Crickley Hill, which is largely derived from the Lias Group and the MMD in Shab Hill which are derived from the FEF but there is no testing available.

5.18.13 Pyrite (FeS_2) is a naturally occurring sulphide mineral that when exposed and disturbed can oxidise to form sulfates. Disturbed ground is defined in BRE SD1 as natural ground that is, for example disturbed by cutting and filling to terrace a site, or by excavation and backfilling, so that air can enter. Simply cutting through ground without opening up the ground beyond the cut face (e.g. piling operations or excavation without backfill) does not generally result in disturbed ground.

5.18.14 For any material that would be disturbed, the total potential sulfate (TPS) must be used to classify the ground for the buried concrete. In accordance with BRE SD1, if only a small number of samples were tested, the highest measured TPS was taken as the characteristic value. In a data set where there are 5 to 9 results available, the mean of the highest two results was taken as the characteristic value. In a data set where there are 10 or more results, the mean of the highest 20% was taken as the characteristic value. For those strata shown to contain pyrite, the results summarised below.

Table 5-29 Summary of the Total Potential Sulfate (TPS) characteristic values for strata shown to contain pyrite

Strata	No. of AS & TS tests	TPS characteristic value (%)
Mass movement deposits (Crickley Hill)	12	8.0
Great Oolite Group – Fuller's Earth Formation	8	4.1
Lias Group – Bridport Sand Formation	4	4.2
Lias Group	8	5.0

5.18.15 As these characteristic values are >2.4%, it would class any disturbed material from these strata as Design Sulfate Class DS-5. However BRE SD1 states that a limitation can be applied if the total potential sulfate is initially found to be DS-5, but sulfate classes for groundwater soluble sulfate (GWS) and the soluble sulfate in 2:1 water / soil extract (WS) are Design Sulfate Class DS-3 or less. In this case, the Design Sulfate Class can be limited to DS-4. The reason for this limitation is that the procedure for sulfate classification based on the total potential sulfate is often highly conservative as not all the pyrite in the disturbed ground would be oxidised. This limitation has been considered when determining the Design Sulfate Class and the Aggressive Chemical Environment for Concrete (ACEC) for these strata.

pH

5.18.16 A total of 48 pH tests were undertaken on soil samples and 65 pH tests undertaken on groundwater samples from the ground investigation. The results are summarised in Table 5-30.

5.18.17 The characteristic values have been determined for each strata in accordance with BRE SD1. If only a small number of soil samples was tested (assumed to be less than 10), the characteristic value was taken as the lowest measured value. Otherwise the mean of the lowest 20% was taken as the characteristic value. For groundwater pH results, the lowest value recorded was taken as the characteristic value. The characteristic value at any given location was taken as the lowest of the soil and groundwater pH characteristic values.

5.18.18 All of the pH test results undertaken on groundwater samples were greater than 7.1 and a worst-case characteristic value of 7.1 has been assumed for groundwater at any location scheme wide.

5.18.19 A summary of the number of pH tests carried out for each stratum and the characteristic values, with and without groundwater is provided below.

Table 5-30 Summary of the number of pH tests carried out for each stratum and the characteristic values

Strata	No of tests	pH characteristic value (without groundwater)	pH characteristic value (with groundwater)
Cheltenham Sand and Gravel	0	n/a	n/a
Mass movement deposits (Shab Hill)	0	n/a	n/a
Mass movement deposits (Crickley Hill)	12	6.5	6.5
Head	2	8.5	7.1
Great Oolite Group – Limestone	4	8.4	7.1
Great Oolite Group – Fuller's Earth Formation	8	7.7	7.1
Inferior Oolite Group	10	7.8	7.1
Lias Group – Bridport Sand Formation	4	7.0	7.0
Lias Group	8	7.7	7.1

5.18.20 When using the characteristic pH values to determine the Aggressive Chemical Environment for Concrete (ACEC) Class, the groundwater is assumed to be either static or mobile. It is assumed scheme wide that the groundwater would be mobile.

Brownfield sites

5.18.21 BRE SD1 states that if a significant number of pH results on a brownfield site are <5.5, the amount of chloride (Cl) and nitrate (NO_3) should be determined to investigate the presence of hydrochloric acid (HCl) and nitric acid (HNO_3). All of the pH values from the ground investigation are > 5.5, therefore no further assessment is required.

5.18.22 If on a brownfield site the sulfate concentration in either the soluble sulfate in 2:1 water / soil extract (WS) or groundwater soluble sulfate (GWS) is greater than 3000mg/l, BRE SD1 states that an additional consideration of the level of magnesium (Mg) is required. All of the soluble sulfate in 2:1 water / soil extract (WS) or groundwater soluble sulfate (GWS) from the ground investigation is less than 3000mg/l, therefore no further assessment is required.

Design Sulfate (DS) and Aggressive Chemical Environment for Concrete (ACEC) Class

5.18.23 The characteristic values for soluble sulfate in 2:1 water / soil extract (WS), groundwater soluble sulfate (GWS) and, for the strata which has been shown to contain pyrite, the total potential sulfate (TPS) have been used to classify the Design Sulfate (DS) Class for each strata. The characteristic value for pH and the groundwater conditions have then been used to assign the Aggressive Chemical Environment for Concrete (ACEC) Class.

5.18.24 A summary of the Design Sulfate (DS) Class and the Aggressive Chemical Environment for Concrete (ACEC) Class for each stratum is provided in Table 5-31.

Table 5-31 Summary of the Design Sulfate (DS) Class and the Aggressive Chemical Environment for Concrete (ACEC) Class for each stratum

Strata	Undisturbed		Disturbed	
	DS Class	ACEC Class	DS Class	ACEC Class
Cheltenham Sand and Gravel	n/a	n/a	n/a	n/a
Mass movement deposits (Shab Hill)	n/a	n/a	n/a	n/a
Mass movement deposits (Crickley Hill)	DS-2	AC-2	DS-4	AC-4
Head Deposits	DS-1	AC-1	DS-1	AC-1
Great Oolite Group – Limestone	DS-1	AC-1	DS-1	AC-1
Great Oolite Group – Fuller's Earth Formation	DS-2	AC-2	DS-4	AC-4
Inferior Oolite Group	DS-1	AC-1	DS-1	AC-1
Lias Group – Bridport Sand Formation	DS-2	AC-2	DS-4	AC-4
Lias Group	DS-2	AC-2	DS-4	AC-4

Note:

- If any buried concrete is in contact with Made Ground, the DS and ACEC class should be assessed on a site-specific basis. Further testing is likely to be required as defined in the Annex A Addendum [4].
- As characteristic pH values are all > 6.5, the ACEC Class is the same for natural or brownfield sites.
- The Design Sulfate (DS) Class of groundwater is DS-1, and the values quoted above assume groundwater is present. The ACEC Class assumes mobile groundwater conditions.
- Disturbed ground is defined in BRE SD1 as natural ground that is, for example disturbed by cutting and filling to terrace a site, or by excavation and backfilling, so that air can enter. Simply cutting through ground without opening up the ground beyond the cut face (e.g. piling operations or excavation without backfill) does not generally result in disturbed ground. The Bridport Sand Formation has encountered voids within the strata that may be classified as disturbed ground. This would need further consideration as part of detailed design.
- Testing of the CSG and the MMD at Shab Hill would need to be carried out as defined in the Annex A Addendum [4].

5.19 Geo-environmental considerations

5.19.1 Construction of the scheme would require significant earthworks and materials movement across the whole of the alignment. Due to the sensitive setting of the scheme with respect to the water environment and ecological receptors, which are dependent on that environment, management of materials potentially impacted by historical and/or current activities would require consideration.

Completed ground investigations and surveys

5.19.2 The proposed scheme has been investigated through scheme specific ground investigation as detailed in Section 4. The geo-environmental assessments have been based on results obtained from the Phase 1 and Phase 2A investigations and surface water surveys, as detailed in Appendix H.

5.19.3 The geo-environmental scope of the ground investigations was informed by information gathered through the PSSR [5]. The PSSR provided an overview of environmental, geological, hydrogeological and hydrological settings of the scheme alignment and the site history. The report concluded that:

"There is no evidence within the historical ground investigation information to suggest that there is any contaminated ground within the confines of either options 12 or 30, according to Section 78R of the Environmental Protection Act 1990. Potential areas of Made Ground have been identified and these will need investigating as part of a project specific ground investigation."

5.19.4 Based on the strategy derived for the intrusive investigations, contamination laboratory testing was undertaken on any encountered made ground materials and/or materials exhibiting visual or olfactory evidence of contamination. A total of 23No soil samples were tested for dry weight suite of analyses and 19No were subjected to soil leachate quality testing. The suite of testing aimed at providing general characterisation of made ground or contamination to allow for assessment of chemical suitability for reuse and assessment of risks to human health and controlled waters during construction and operation. Refer to Appendix H for details on completed geo-environmental investigations.

Conceptual site model and completed risk assessments

5.19.5 Assessment of risks in relation to contamination were undertaken in accordance with industry best practice presented in Land Contamination Risk Management guidance (replacing CLR11 [26]). The risk assessment process has been underpinned throughout by the development of the conceptual site model (CSM), which provides a schematic representation of the identified contaminant linkages. A Conceptual Site Model for the scheme is presented in Appendix H.

5.19.6 The risk assessment process has entailed a tiered approach, which comprised a Tier 1: Preliminary Risk Assessment (PRA) and a Tier 2: Generic Quantitative Risk Assessment. Any potential risks identified at Tier 1 were studied in more detail through a Tier 2 assessment. The methodology and assessments are presented in Appendix H. The conclusions of the assessments are summarised below.

5.19.7 The completed risk assessments have not identified unacceptable risks with respect to the scheme end users. The identified risks can be managed by appropriate health and safety measures (refer to sections on Health and Safety Management) and materials management (refer to sections on Materials reuse).

5.19.8 The completed risk assessments identified a number of exceedances within analysed samples of groundwater and surface water. The hydrogeological model derived for the scheme (refer to Section 5.17), indicates surface water being recharged by groundwater through springs, particularly the tributary of Norman's Brook in Crickley Hill. Generally, the identified exceedances of the applied assessment criteria in groundwater are not considered significant and the surface water testing results do not indicate that the groundwater is currently have a detrimental impact on surface water quality. However, during construction works site specific consideration of groundwater chemical composition would be required to inform dewatering activities, particularly discharge of removed groundwater, where necessary; and where new drainage is introduced, which would intercept groundwater and conveyed it directly into the water course.

5.19.9 The groundwater quality has however been locally impacted by hydrocarbon contamination, PAH compounds and/or petroleum hydrocarbons. In addition, evidence of hydrocarbon contamination has been recorded in made ground encountered in the Grove Farm/Crickley Hill and areas of car parking or road network. In addition, there is a potential risk that the historical landfill cell may impact the groundwater quality.

5.19.10 The following areas of concern have been identified:

- Area of OH416 and DSRC415 due to elevated concentrations of PAHs and petroleum hydrocarbons in groundwater and soils, potential sources - existing A417, accidental fuel spillages or leakages from agricultural machinery or made ground (tarmacadam). The scheme proposals are for repurposing the existing A417 into an active travel route with increased landscaping in the vicinity of OH416 and DSRC415. Increased rainwater infiltration may result in mobilisation of contaminants to groundwater. The existing drainage associated with A417 is to remain in place, however the inflows would be reduced and of better quality, subsequently potentially reducing the contaminants discharge into groundwater. Further assessments to confirm the source and risks are required.
- Area of DSRC403 due to detected concentrations of petroleum hydrocarbons in groundwater, potential source - existing A417. The scheme proposals are for a new drainage channel to run in the vicinity of DSRC403 (Ch 5+500). The recorded detectable concentrations of petroleum hydrocarbons may be indicative of a source of hydrocarbon contamination within the area of the scheme. The identified presence of hydrocarbon contamination would require consideration during scheme construction, particularly should dewatering be required. Further assessments to confirm the source and risks is required.
- Area of DSRC229 due to elevated concentrations of petroleum hydrocarbons in groundwater, potential sources – off-site, not identified, potentially associated with nearby properties e.g. a heating oil storage tank. Installation of horizontal drainage as part of the northern slope stabilisation measures (approximately Ch 0+700 to Ch 1+700) may provide a direct pathway for that contaminated groundwater into the tributary of Norman’s Brook. Further assessment to confirm the source and risks is required.
- Area of Grove Farm (approximately Ch 1+400 to Ch 1+600) due to recorded evidence of hydrocarbon contamination in made ground such as ash, slag, clinker, charcoal or odours. These materials may pose a risk to controlled waters and therefore are not considered suitable for reuse in landscaped areas or close proximity to surface water receptors.
- Area immediately south of one of the cells of the historical landfill (Ch 0+950) has not been investigated due to access issues and therefore no information is available on groundwater quality within the scheme area to the north of Ch 0+950. Introduction of the slope stabilisation measures (drainage) from approximately Ch0+700 to Ch1+700 may introduce a preferential flow path into the tributary of Norman’s Brook. Further assessments to confirm the source and risks is required.

5.19.11 These areas of concern are considered to be localised and of limited extent. However, further investigations and assessments will be undertaken as defined in the Annex A Addendum [4] to further understand the risks to the identified controlled water receptors. If risks are found unacceptable, remediation will be necessary, as detailed in sections on Remediation requirements.

Materials reuse

5.19.12 Based on current proposals, it is understood that materials arising from the excavation works are to be used within the scheme. The management of materials during construction would be undertaken in accordance with Annex E Materials management plan of ES Appendix 2.1 Environmental management plan (Document Reference 6.4). The MMP would incorporate any remediation strategies derived for the scheme.

5.19.13 Only materials that do not pose a significant risk to end site users or controlled water receptors are considered suitable for reuse. Based on the findings of the assessments, the encountered materials to date are considered to be chemically suitable for reuse, subject to appropriate verification process and with the following limitations:

- Made ground impacted by tarmacadam or removed from areas with tarmacadam at surface may pose a risk to human health during operation if e.g. used at surface in landscaped areas. Therefore, the reuse of tarmacadam impacted materials would be limited to placement at depth e.g. 300mm.
- Made ground exhibiting evidence of hydrocarbon contamination such as tarmacadam, ash, slag, clinker, charcoal or odours. These materials may pose a risk to controlled waters and therefore are not considered suitable for reuse in landscaped areas or in close proximity to surface water receptors.
- Materials exhibiting evidence of significant contamination e.g. containing bulk asbestos (i.e. ACM - asbestos containing materials) or visual contamination with free phase petroleum hydrocarbons are not considered suitable for reuse within the scheme without treatment.

Disposal options

5.19.14 Any surplus or unsuitable materials would require off-site disposal at a suitable licenced facility. The management of such waste would be governed by Annex H Site waste management plan ES Appendix 2.1 Environmental management plan (Document Reference 6.4).

5.19.15 Should off-site disposal be required, the materials would be characterised in accordance with the Environment Agency's Technical Guidance WM3. This may require further sampling and testing of soils to obtain appropriate dry weight and WAC testing. Testing requirement may vary depending on disposal option. It is recommended that disposal at landfill is considered as a last resort with reuse/recycling considered first. Disposal at soil recycling or waste transfer stations may attract different testing requirements.

5.19.16 Based on the ground conditions encountered to date, the majority of the surplus materials are likely to comprise natural soils. In accordance with current waste management guidance, these materials are likely to be suitable for inert landfill disposal without testing.

5.19.17 There is potential to encounter hazardous waste in areas of concern as listed in Section 5.19.10. Materials exhibiting evidence of hydrocarbon contamination may require disposal at hazardous waste facilities. Prior to disposal materials would require testing and waste classification assessment.

Remediation Requirements

5.19.18 Based on currently available information, no significant and widespread contamination has been encountered and no requirement for extensive remedial works is expected. However, localised areas of contamination have been identified, as listed in section 5.19.10.

5.19.19 These areas of concern would be subject to a Tier 3: Detailed Quantitative Risk Assessment (DQRA) to confirm the risks, identify and delineate the sources and quantify the risks to identified receptors. Based on the results of the Tier 3: DQRA, a remediation strategy would be developed to remove unacceptable risks, where required. The detailed assessments would be completed at detailed design.

5.19.20 Remediation works, if required, would be undertaken during construction followed on by a verification process set out in a remediation implementation and verification plan. Verification may involve monitoring or targeted investigations to confirm that the remediation works have achieved the objectives. On completion of the works, a verification report would be prepared. The remediation strategy, remediation implementation and verification plan and verification report would form part of the Annex E Materials management plan of ES Appendix 2.1 Environmental management plan (Document Reference 6.4) and allow appropriate classification and management of contaminated materials during construction.

Unexpected contamination

5.19.21 Areas of unexpected contamination may be encountered during construction particularly in areas of the existing A417 as a result of current land use due to accidental fuel spillages or leakage, or in areas of the existing highway drainage. Therefore, a watching brief would be adopted to allow for appropriate management of contaminated materials to limit the risk to human health, controlled waters and allow for containment of contamination. An action plan would be developed to set out procedures and responsibilities and would form part of the Annex E Materials management plan of ES Appendix 2.1 Environmental management plan (Document Reference 6.4). As a minimum the plan should allow for assessment of encountered contamination in liaison with a suitably qualified land contamination specialist, revision of health and safety measures, identification of a designated storage area within the site compound, sampling and testing of the potentially contaminated materials part of materials classification process, verification process.

5.19.22 Management of made ground materials should also consider the recommendations of CIRIA C765 good practice site guide on management of asbestos in soil and made ground.

Health and Safety Management

5.19.23 Based on the findings of the human health risk assessment (as presented in Appendix H) materials exhibiting visual and olfactory evidence of hydrocarbon contamination may pose a risk to site personnel and scheme neighbours during construction, and maintenance workers during operation. Stripping, processing and crushing of tarmacadam will also require specific measures to avoid dust generation. During excavations care should be taken to segregate and separate tarmacadam from underlying soils.

5.19.24 Therefore, during construction, health and safety risk assessments should consider available desk study information as well as results of intrusive ground investigations (records of evidence of contamination, location, and nature of areas of concern, chemical testing results) to identify appropriate mitigation measures.

5.19.25 Unexpected contamination may also be encountered during construction. As part of the Annex E Materials management plan of ES Appendix 2.1 Environmental management plan (Document Reference 6.4), the contractor would be required to prepare an action plan setting out procedures for dealing with unexpected contamination including a review of health and safety procedures, see Section 5.19.24.

6 Geotechnical risk register

6.1.1 The Geotechnical Risk Register is included in Appendix I. The risk register should be reviewed and updated throughout the detailed design and construction phase to allow the identified risks to be most effectively managed and appropriate mitigation to be considered throughout the design and construction process.

7 Engineering assessment and recommendations

7.1 General

7.1.1 The following section presents an engineering assessment for the scheme based on the findings and recommendations of this GIR. The assessment presents a summary of the geotechnical design elements that have been assessed as part of the Stage 3 design and provides details extra over to that normally included in a GIR. This has been developed to inform the assessment of environmental impact, and scheme costs and risks, and to allow the scheme boundary to be defined for the DCO. All proposals would need to be reviewed and refined at the detailed design stage.

7.1.2 Note that in some areas, as identified throughout this GIR, some elements of the scope of proposed ground investigation remained to be undertaken when this report was prepared. This GIR and Engineering Assessment will be updated once this further investigation data is available. Additional recommended ground investigation has been defined in the Annex A Addendum [4].

7.1.3 The impacts of the geotechnical risks presented in Section 6 on the engineering elements for the scheme are discussed in this section. In addition, any further requirements for ground investigation have been highlighted.

7.1.4 The scheme elements discussed in this section include:

- Earthworks – cuttings
- Earthworks – embankments
- Wider slope stability – Ch 0+500 to Ch 1+750 Crickley Hill
- Geotechnical recommendations for drainage features
- Recommended CBRs for pavement design
- Structure foundations and retaining walls

7.1.5 Schematic figures are included in the section to illustrate the design features in relation to the ground conditions and geotechnical risks identified in this GIR.

7.2 Earthworks – cuttings

Cut slope stability

7.2.1 Several cutting slopes are proposed from Ch 1+700 to Ch 5+300. Cut associated with drainage features such as attenuation ponds and the relocated tributary of Norman's Brook are proposed and are discussed further in Section 7.5.

7.2.2 Table 7-1 presents the Stage 3 mainline cut geometries, the strata comprising the cut slopes and further considerations for these strata.

Table 7-1 Summary of considerations for proposed cuts

Cut material and proposed cut geometry (Cut chainage extent in brackets)	Further considerations
CSG (Ch0+000 to 0+500) Max cut height: 2.5m	Cuts up to 1m high are required where existing cut is required to be widened. Additionally, a cut of around 2.5m is proposed for an attenuation pond

Cut material and proposed cut geometry (Cut chainage extent in brackets)	Further considerations
MMD (Ch1+700 to Ch1+750) 35° cut slope Max cut height: 22m	The extent of the MMD within the cut slope is unknown and stabilisation measures such as soil nails may be required. The existing cut slope of similar height to the proposed is a 35° slope with no stabilisation measures. As part of the detailed design additional GI may delineate the thickness of MMD in combination with clearance of the slope for a detailed inspection.
Inferior Oolite Group (Ch1+740 to Ch 2+910) Predominantly 60° cut slope benched at 5m cut height intervals to give an overall 35° cut slope Varying to 18° Max cut height: 21m	Observational approach to cut formation to be considered at detailed design to account for variability in rock strength and quality over the depth of the cut. An illustration of the observational approach concept is presented in Figure 7-1. Rock mass quality reduced approaching the Shab Hill Fault – potential that an overall flat 35° may be required. Rock fall likely to occur over the design life of the cut and would impact the overall appearance of the cut over the design life. Rock catch fence/wall likely to be required within the verges at the base of the cutting slopes. Periodic maintenance may be required. Potential for gulls to be encountered and consideration on gull infill treatment would be required in the form of granular fill with a mass concrete or grout plug. Mitigation measures should be in accordance with the karst protocol for the scheme. Gulls have not been explicitly identified in the ground investigation but have been encountered historically in the Birdlip bypass scheme at Barrow Wake [23]. The potential for dissolution voids has been identified and there may be a risk that larger dissolution features are present. Void treatment measures within the cut face such as dentition and within the cut floor (i.e. infill and geogrids) would need to be considered. The discontinuity data suggests overbreak at the cut formation level may occur that would require treatment measures such as regulating layers to be developed. [Note that during the construction of the Birdlip bypass scheme [23], there were difficulties in achieving the formation level with significant overbreak and a regulating layer of rock fill (around 300mm thick) was required to make up the formation level The initial part of the cut is located towards the base of the Inferior Oolite where groundwater has been monitored close to this level. There is potential that control of groundwater from the cut face may be required. Over this extent there could be potential to encounter the Bridport Sand Formation within the cut base that is water bearing and potentially has voids. In addition to drainage measures consideration for the treatment of voids in the form of backfill and spanning with geogrids would need to be considered.

Cut material and proposed cut geometry (Cut chainage extent in brackets)	Further considerations
	Overlying head material varies in thickness resulting in varying upper soil cut above the rock.
Great Oolite Group (Various from Ch3+520 to 5+300) 18° cut slope benched (6m wide bench) at 5m cut height intervals Max cut height: 8.5m	Combination of rock (limestone / mudstone) and weathered rock to soil likely to be encountered in cut face that would lead to irregular face after excavation and over time due to weathering. Localised stabilisation measures such as dentition would need to be adopted. Any breakdown of the cut face material over time would need to be considered as part of the design. The presence of low strength zones may occur, but the overall cut geometry should mitigate this risk. The risk of any instability from these zones would need to be addressed in the form of slackening the slope further or slope stabilisation. [Note that existing cut slopes within similar stratigraphy in the area such as the Parson's Pitch cut (Birdlip Bypass Scheme [23]) have been cut at 1:3 (18°) with no reported instability issues].

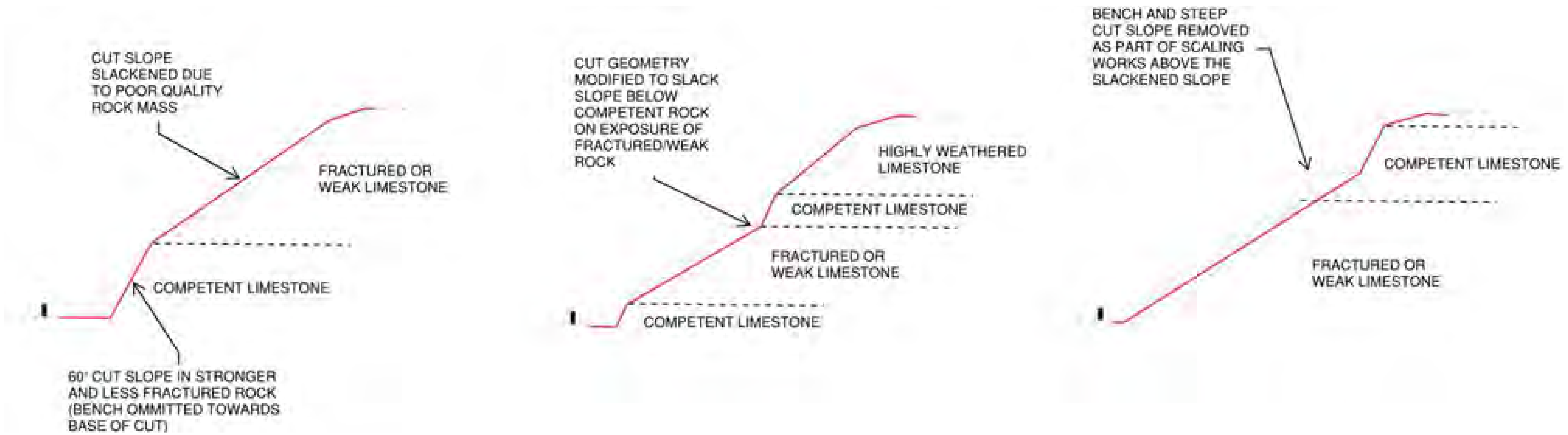

Figure 7-1 Illustration of the observational approach during cutting excavation

Material reuse

7.2.3 The following summarises the considerations related to material reuse for the main cut materials.

Table 7-2 Summary of considerations for proposed cuts

Cut material	Material reuse considerations
Cheltenham Sands and Gravels	Natural moisture content wet of optimum and potential drying of excavated material may be required.
Mass Movement Deposits – Crickley Hill	Potential to reuse as Class 2 general fill but potential risk of excessive organic matter content or high moisture content locally rendering this material unsuitable for re-use as engineering fill. [Note that for the nearby Brockworth bypass scheme [28] the MMD was classified as landscape fill. Limited compaction testing indicates that the natural moisture content would be wet of the OMC – possible treatment in the form of drying].
Inferior Oolite Group	Potential to reuse as a Class1B/1C general fill. Aggregate testing (LA Coefficient) generally below 50% and as such material may be borderline to use as a select fill (potential to zone areas). Appropriate bulking factors would need to be developed to account for an increase in material volume from the in-situ to compacted condition. [Construction records for the adjoining Nettleton to Latton scheme [29] indicate limestone should be suitable as general fill but processing of excavated material required to achieve grading requirement (lack of sand and gravel sizes material) but breakdown of the material reported after placement, compaction and tracking resulting in a compliant material].
Great Oolite Group – Limestone	Potential to reuse as a Class1B/1C general fill but extent within cuts anticipated to be limited. Appropriate bulking factors would need to be developed to account for an increase in material volume from the in-situ to compacted condition. [Construction records for the adjoining Nettleton to Latton scheme [29] indicate limestone should be suitable as general fill but processing of excavated material required to achieve grading requirement (lack of sand and gravel sizes material) but breakdown of the material reported after placement, compaction and tracking resulting in a compliant material].
Great Oolite Group – Fuller's Earth Formation	Potential to re-use as a Class 2 general fill. Potential to segregate limestone from mudstone but the proportion of limestone to mudstone/clay would need evaluation to understand if viable. Natural moisture content wet of optimum and potential drying of excavated material may be required [Birdlip bypass scheme [23] reported Fuller's Earth is moisture susceptible. Stockpiling and formation protection would be required].

7.2.4 Geo-environmental considerations with respect to materials management during construction including suitability for reuse of made ground materials, dealing with unexpected contamination, remediation requirements and disposal are presented in Section 5.19.

7.3 Earthworks – embankments

7.3.1 The embankments across the scheme are to be constructed at side slopes of 18^{o} (1 vertical to 3 horizontal). Landscape bunds are proposed along Crickley Hill and south of the Shab Hill Junctions with side slopes varying from 7^{o} (1:8) to 18^{o} (1:3). Embankment heights are likely to vary from 1m to 22m.

7.3.2 The long-term stability of the embankments is dependent on the height of the embankments and the fill type used to form the embankment. The excavated material won would predominantly be Inferior Oolite Group material that would behave as a granular fill. Fill material from the Fuller's Earth Formation would likely have cohesive long-term strength parameters that may change due to breakdown or weathering.

7.3.3 Based on the ground conditions identified in this GIR, the following summarises considerations for embankments.

- Crickley Hill valley
  - Soft clay has been identified valley near the existing tributary of Norman's Brook. The soft material is within the MMD and may be isolated towards the watercourse. Stability and settlement of the embankments overlying the material would need to be addressed. There is potential that the soft material is isolated in occurrence but further GI along the centreline of the scheme would be required to assess the soft soil and potential alluvium extent and would need to incorporated as defined in the Annex A Addendum [4].
  - The proposed embankment would likely cover springs emerging from the valley sides. It is anticipated that a drainage blanket/starter layer would need to be incorporated at the base of the embankments.
  - The proposed embankment would cover the existing tributary of Norman's Brook. Flows would need to be maintained through the existing watercourse that would also intercept flows below the embankment from the drainage blanket. To facilitate this, backfill of the existing water course with drainage fill would be required.
- Shab Hill
  - Soft MMD have been identified within the Shab Hill dry valley. Treatment in the form of excavation and replacement of soft materials would likely be required
  - The proposed embankment has the potential to cover existing springs or block surface water down the valley sides. A basal drainage layer/starter layer would be required.
- Stockwell overbridge approach embankment
  - The western approach embankment would be constructed on side long ground. Potential solifluction or slip material may be present associated with the Fuller's Earth Formation. Consideration for ground treatment to the

embankment in the form of dig and replace or lightweight fill embankment construction would be required.

7.4 Wider slope stability - Crickley Hill

General

7.4.1 From Ch 0+500 to Ch 1+700 the scheme is flanked by the northern and southern slopes of the Crickley Hill valley and the Cotswold escarpment. The formation of the valley slopes has been attributed to periglacial conditions causing some or a combination of the following mechanism (for further detail reference to the PSSR [5] should be made):

- Deep seated rotational failures within the Lias Group resulting in cambered limestone blocks. The depth of the failures is ether restricted by the Marlstone Rock Formation or has penetrated through it and disturbed the formation.
- Shallower rotational / translational / slumping failures within the larger slip mass. This has caused movement and weathering of the cambered limestone blocks within the slip mass as illustrated in Figure 7-2.

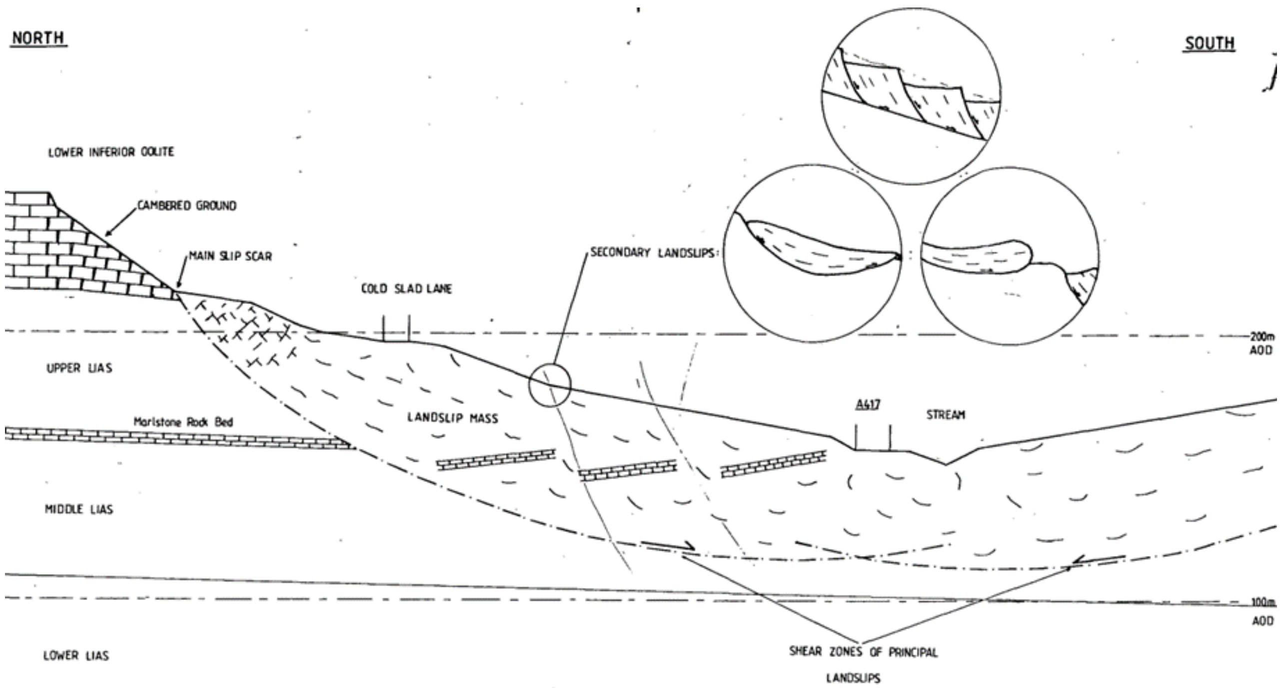

Figure 7-2 Illustration of landslide geometry and features from Wilson [30]

Note: The terminology used for the strata described in this figure has been superseded as set out in this report

7.4.2 Literature presented in the PSSR [5] suggests that the valley slopes are marginally stable. There is evidence of ongoing slope movements within the mass movement deposits. This includes concave breaks of slope, backscarps and leaning trees, debris flow lobes, often associated with springs, and indicative of recent relatively shallow slope movement processes. There is also evidence of ongoing movements to the order of 5mm/year to depths of 9 to 20m from the inclinometer data, as discussed in Section 5.9.

7.4.3 The following presents a qualitative review of the impact the wider slopes in the Crickley Hill valley could have on the scheme and any further considerations for detailed design. The qualitative review broadly follows slope stability risk assessment procedures [31] by reviewing the following:

- Anticipated hazards
- Triggers for slope instability
- Impact on the scheme
- Mitigation

Potential hazards

7.4.4 The geomorphological mapping (refer to Appendix A) and the ground condition interpretation for the Crickley Hill MMD and the underlying Lias Group have been used to inform the likely hazards present across the Crickley Hill valley slopes. A number of "slope hazard" zones have been identified as part of the geomorphological mapping (refer to Appendix A). Table 7-3 summarises the anticipated hazards.

Table 7-3 Summary of potential hazards within the Crickley Hill wider valley slopes

Hazard	Description	Features based on mapping / interpretation
Rockfall	Cliff face exposure at top of the escarpment Exposed blocks of Inferior Oolite in cambered slope	Scree slopes at base of Inferior Oolite exposures Exposed oolite blocks above ground surface in the slope based on site observations (Main hazard on northern slope associated with previous works from Ch 1+650 to 1+750)
Deep seated landslide	Associated with cambering of the Inferior Oolite and failure through the underlying Lias Group (slips more than 50m in depth)	Tilted blocks of Inferior Oolite towards the upper reach of the slopes near the escarpment. Infilled gulls mapped within the escarpment – potentially indicative of deep-seated movements Varying levels of Marlstone Rock Formation in the exploratory holes – potential disturbance from deep seated movements (Not anticipated from Ch 0+500 to Ch 0+900 based on site observations)
Shallow landslides	Rotational or planar landslides within the MMD: Small (5 to 20m scarp width, <5m slip depth) Medium (up to 30 to 40m scarp width, 5 to 10m slip depth) Large (>50m scarp width, 10 to 15m slip depth) (Note slip sizes are measured estimates based on the geomorphological mapping – potential for larger slip surfaces to 25m based on published interpretations)	Multiple features (up to 30+ within each slope zone mapped) observed as: • Concave breaks in slope • Back scarps (often aligned with springs or tilting trees) • Landslide toes Based on data from exploratory holes and geophysical surveys, the depth of MMD varies along the slopes, but with typical thicknesses of between 10 and 20m. The depth of the inclinometer movements broadly ties in with anticipated depths of the shallow landslides and indicate small on-going movements of the slip mass. Run out lengths for recent landslip features (where not obscured by other features) 10 to 50m long

Hazard	Description	Features based on mapping / interpretation
		Distance to existing A417 varies from 10m to 100m
Debris flow	Flow lobes within MMD Loose spoil at foot of escarpment cliff	Lobate and irregular features generally 10 to 100m long, 10 to 20m wide and based on geomorphological evidence judged to be shallow features e.g. less than 5m deep. (Less features observed on southern valley slope relative to northern slope)

Triggers

7.4.5 The key trigger for slope movements is anticipated to be related to increases in porewater pressures within the slopes following heavy rainfall events. The following are observations from the hydrogeology assessment (refer to Section 5.17):

- Monthly rainfall from February 2018 to May 2019 is below the monthly rainfall average for the Cotswold area. From June 2019 to October 2020 higher than average monthly rainfall was recorded.
- Groundwater within the MMD can be attributed to groundwater fed from the Inferior Oolite and rainfall infiltration. Within the MMD groundwater levels are either shallow (<3m depth) or deeper (around 10m depth) The shallower groundwater is attributed to trapped water within more permeable zones of material derived from the Inferior Oolite within the surface of the generally more cohesive slip mass.
- The groundwater monitoring suggests a seasonal variation in the groundwater level within the MMD and in some cases responses to heavier rainfall events has been recorded. A similar seasonal variation in groundwater within the underlying Lias Group has been recorded but little responsiveness to rainfall.
- The inclinometer monitoring covers the period June 2019 to November 2020. In general, movements have increased (from <1mm up to 9mm) during the monitoring period with increases in movement generally beginning from around December 2019. This corresponds to a continual rise in monthly rainfall

7.4.6 Slope movement associated with the debris flows are likely to be due to saturation and weathering of the material causing gravity-based movement downslope.

7.4.7 Frost shattering of the exposed limestone is considered the trigger for rockfall.

7.4.8 There is anticipated that seasonal rises in the shallow and deeper groundwater levels and corresponding increases in pore water pressures within the MMD may be the trigger for slope instability (associated with the “shallow landslide” hazards (refer to Table 7-3)). No instances of slope instability have been recorded over the site works and groundwater / inclinometer monitoring period (June 2019 to November 2020). It is anticipated that a continued and sustained period of extreme rainfall would be required (greater than observed over the monitoring period) to trigger large displacement slope movements. It is anticipated that such conditions could occur during the design life of the scheme.

7.4.9 The deep seated movements within the slopes are understood to have occurred during extreme climatic events, i.e. during periglacial conditions [10]. During this time, the porewater pressures within the slopes will have been greater and the materials within the slopes also potentially of lower strength. It is not expected that changes in groundwater that may occur during current climatic conditions are likely to reactivate deep seated slope movements. As such reactivation of the deep seated slips is not considered credible.

7.4.10 Earthworks such as cutting into the existing slopes are likely to trigger instability and embankments positioned within the slope away from the toe. The proposed scheme has avoided cuts into the existing slopes and embankments within the wider slopes and as such there is a low likelihood of triggering instability due to the proposed earthworks.

Scheme impact from instability

7.4.11 The scheme elements that are potentially at risk from slope instability from Ch 0+500 to Ch 1+700 are summarised below:

- A417 mainline
- Cold Slad Lane
- Relocated Normans Brook
- Attenuation pond at Ch 1+500

7.4.12 The risk posed to the above scheme elements depends on the geometry of the proposed scheme relative to the predicted run out extents and volumes of the shallow landslide and debris flow hazards.

7.4.13 Based on the predicted run out distance of the shallow landslides and the debris flow based on the geomorphological mapping (measured from the back scarp to the toe of the landslide), it is anticipated that shallow landslides occurring within 50m of the scheme earthworks footprint could feasibly reach and impact the scheme. Based on typical sections, Figure 7-3 illustrates the impact of the large shallow landslide from the northern slopes on Cold Slad Lane and the A417 mainline.

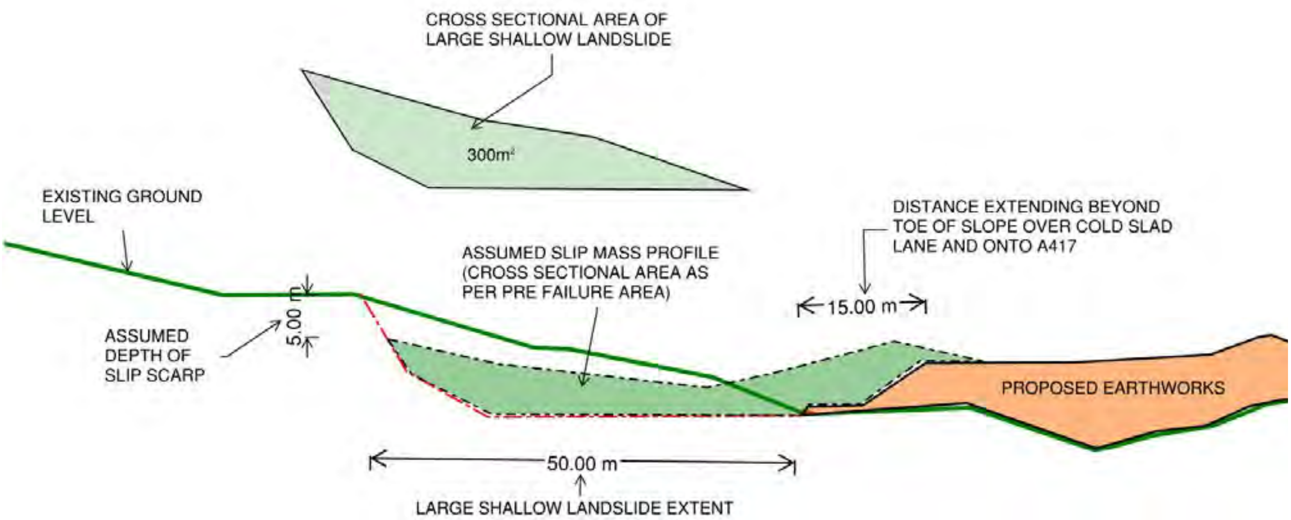

Figure 7-3 Illustration of large shallow landslide hazard on Cold Slad Lane and A417

7.4.14 Figure 7-3 illustrates that that Cold Slad Lane and the A417 have the potential to be impacted by 'large shallow landslides' (refer to Table 7-3). Based on the cross-sectional areas of the small and intermediate shallow landslides it is likely that Cold Slad Lane may be impacted by these smaller scale slips, but these smaller features are unlikely to impact on the A417 mainline highway that is raised up on the proposed embankment.

7.4.15 For the southern slopes the impact of the shallow landslides (all sizes) would be on the relocated Normans Brook however, mapped failures are typically further up slope and to the south and there is limited evidence of slope failures within 50m of the scheme.

7.4.16 Mass movement deposits have been identified below the proposed earthworks footprint (refer to Section 5.9). The risk of land sliding below the scheme would likely be mitigated by loading of the toe of the landslip mass by the proposed embankment. This would lower the risk compared to the existing road alignment.

7.4.17 For the other hazards identified the following summarises the likely impact:

- Rockfall – over the majority of the Crickley Hill section, rockfall is unlikely to impact the scheme. The exception is the existing cut adjacent to the scheme from Ch1+650 to 1+750.
- Deep seated landslides – if failure occurs then the hazard could impact the scheme. As discussed above groundwater is likely to be the main trigger and it is considered the event required to trigger failure is likely to be a very low probability event.

Mitigation

7.4.18 Based on the above there is a risk that slope instability could impact the scheme. Ground stabilisation measures are required to manage this risk. The installation of inclined groundwater drainage within the northern slopes and part of the southern slopes is proposed to control the ground water level within the slope and mitigate the risk of potential ground instability. The slope drainage would likely be required over the following extents:

- Ch 0+680 to Ch 1+730, northern slopes
- Ch 0+820 to Ch 1+050, southern slopes

7.4.19 The proposed slope drainage would comprise shallow inclined perforated drainage pipes which would be installed by drilling into the slope from the highway verge with any groundwater flows channelled into the highway drainage. The aim of the slope drainage would be to prevent the build-up of the shallow ground water level during prolonged rainfall events. This would mitigate against triggering of the shallow landslides. The length of the drains is around 50m, located over the length of likely slip mass run out (measured from the back scarp to the toe of the landslide) that could impact on the scheme. The concept is illustrated in Figure 7-4.

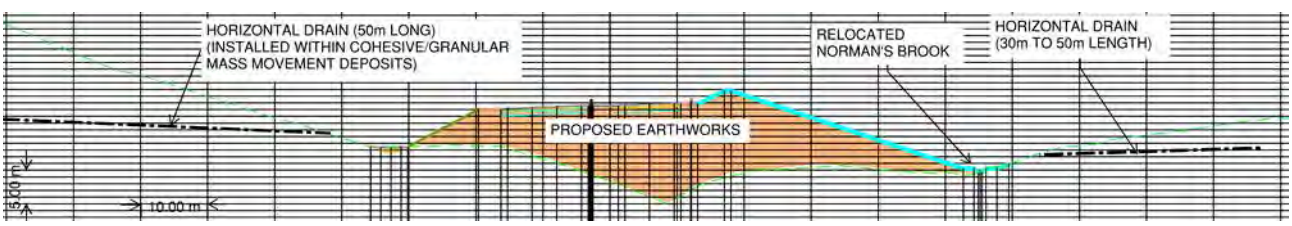

Figure 7-4 Illustration of slope drainage measures (northern and southern slopes)

7.4.20 The detailed design would need to consider the following:

- Drains would be installed into predominantly cohesive MMD, intersecting more permeable lenses and inclusions within the slope – the variability of the material would need to be considered in the design of the horizontal drain spacing.
- Splaying (in plan) of a number of drains from one drilling point to increase the horizontal spacing between drilling points or to avoid surface features such as properties.
- Maintenance of the drains would be required in the form of cleaning and inspection – access provisions would be required.

7.4.21 Other points that would need to be considered as part of the detailed design of ground stabilisation measures along Crickley Hill include:

- Periodic inspection and potentially clearance of any slip debris moving into the relocated tributary of Normans Brook where no slope drainage is proposed.
- Installation and ongoing inspection of other slope stabilisation measures (such as soil nails) where historical localised cut into the MMD has occurred.
- Scaling during construction and periodic inspection of rock fall hazards on the exiting slopes from Ch 1+650 to CH 1+750.

7.4.22 As part of the detailed design a quantitative slope stability risk assessment is recommended to assess the outcomes of the qualitative assessment presented in this GIR. The values attributed to the risk outcomes may be such that ground stabilisation measures are not required and that monitoring of the wider slopes could be a method to manage the risk to the scheme.

7.5 Geotechnical considerations for drainage features

7.5.1 Drainage features that require geotechnical consideration comprise:

- Attenuation ponds
- Relocated tributary of Norman's Brook

7.5.2 Attenuation ponds are proposed that are to be partially excavated to depths of 2.5 to 9m into the existing ground. The attenuation pond design would need to consider the following:

- Stability of the pond excavation and the associated implications on the stability of the mainline earthworks adjacent to the ponds.
- Lining of proposed attenuation ponds in the following areas:
  - The Inferior Oolite Group and Great Oolite Group. Lining of the ponds would likely be required to ensure separation of the highway drainage from the aquifers associated with each of these strata. Lining would also prevent washout of silt infilled karst features which could trigger ground subsidence or further dissolution of the limestone over time.
  - Attenuation ponds within the MMD would need to be lined to avoid introducing water into the slopes which could locally increase groundwater levels and porewater pressures within the MMD that may trigger slope instability.
  - Shab Hill junction fill embankment to avoid infiltration into the embankment that may cause erosion of the embankment shoulders and subsequent instability.

7.5.3 The tributary of Norman's Brook is to be relocated further up the southern valley slope where the proposed embankment toe intersects the existing valley slope. The relocated watercourse is to intercept surface water from the southern valley slope. To ensure flows within the relocated watercourse (for environmental purposes), it is likely that water infiltrating into the existing tributary of Normans Brook alignment (backfilled with drainage fill under the embankment (refer to Section 7.3)) may need to be channelled to the relocated position. The incorporation of "drainage spurs" running from the existing to new watercourse position may be required, as illustrated in Figure 7-5.

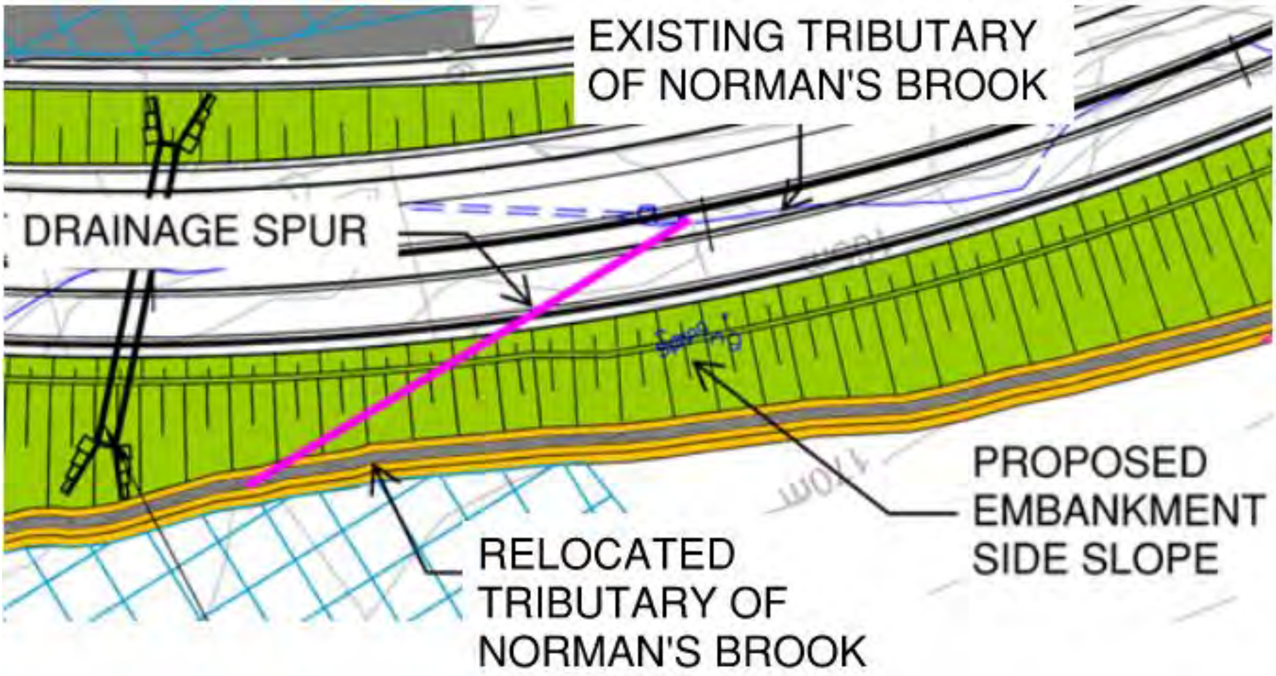

Figure 7-5 Illustration of drainage spur connecting existing tributary of Norman's Brook (uphill) to the relocated position (downhill)

7.5.4 Design and construction of the "drainage spurs" would need to consider drainage falls, drainage lengths and interaction with the drainage blanket layer below the embankment. Periodic inspection would also be required to ensure there are no blockages to the relocated water course (from potential slope instability) and that the "drainage spur" system is operational.

7.6 Recommended CBR values for pavement design

The proposed CBR for pavement design is to be assessed as part of the detailed design. The following are some preliminary indications of CBRs for strata forming the pavement subgrade based on the findings of this GIR and recommendations in TRL Report LR1132 [32]. With the exception of the rock associated with the Inferior Oolite Group and the Great Oolite Group limestone, the following strata are cohesive materials and the average plasticity index for each has been used as presented within Section 5.

Table 7-4 Summary of CBR values

Strata	Proposed CBR range
Cheltenham Sand and Gravel	3 to 5%
Head Deposits (Inferior Oolite Group)	4 to 5%

Strata	Proposed CBR range
Head Deposits (Fuller's Earth Formation)	2.5 to 3%
Great Oolite Group – Fuller's Earth Formation	2.5 to 3%
Rock associated with Inferior Oolite Group or Great Oolite Group limestone	>10% (estimated)

7.7 Structure foundations

Table 7-5 presents a list of the proposed structures along the scheme and the likely foundations based on the anticipated ground conditions with any associated geotechnical considerations.

Table 7-5 Summary of proposed structures and likely foundations

Chainage	Structure	Foundation type and considerations
CH 1+100	Bat underpass east of Fly-Up	The structure is anticipated to be underlain by Mass Movement Deposits (MMD) overlying the Lias Group based on the geological plans. Localised alluvial deposits may also be encountered close to Normans Brook. No significant cutting is anticipated to be required to form the structure; however even small-scale excavations into the MMD may require some temporary support to prevent any slope instability. The base of the precast concrete box sections and the L-shaped precast wing walls would act as foundations. The southern part of the structure would be constructed entirely within engineered embankment fill overlying the natural ground level, while the northern part would be close to the existing ground level. Any localised soft material beneath the structure would be removed and replaced with engineered fill (as part of the earthworks to form the embankment and divert the tributary of Norman's Brook). Earthworks and foundation ground requirements at the structure location (and structure sensitivity to any differential ground movements) would need to be reviewed in detail at next design stage. Also see specific hazard and risk items 9, 17, 18, 24, 26 & 39 in Appendix I of this GIR.
CH 1+725	Grove Farm underpass	The structure is anticipated to be underlain by Mass Movement Deposits (MMD) overlying the Lias Group, based on the geological plans and the available ground investigation information. The structure would be constructed predominantly within the proposed embankment with the exception of the northern end of the structure requiring some cutting into the existing slopes. This localised cutting is not considered at this stage to create a significant slope stability risk; however, this would need to be reviewed in detail in the next design phase, taking into account also the earthworks/regrading proposals to form the southern access to the underpass. At this stage it is assumed that the structure would be supported on shallow foundations. However, this would need to be reviewed following additional ground investigation proposed at the structure location (there is a risk that piled foundations may be required). Also See Risk items 9, 18, 26 & 40 in Appendix I of this GIR.

Chainage	Structure	Foundation type and considerations
CH 2+000	Cotswold Way crossing	The structure is anticipated to be underlain by Birdlip Limestone Formation of the Inferior Oolite Group based on the geological plans and the available ground investigation information (limited to the southern abutment area). The proposed road is in cutting at the structure location. The foundations for the abutments and the intermediate piers are anticipated to be sitting on limestone rock, which is assumed to be suitable for a spread foundation solution. The potential presence of dissolution voids, which are more prevalent towards the base of the Birdlip Limestone Formation would however need to be considered at detailed design stage. At the intermediate pier and the northern abutment foundations there is a risk that suitable rock formation be deeper than anticipated, requiring some deeper excavations and backfilling works. This would need to be assessed more in detail at the next design stage, in the light of the further ground investigation proposed. The southern abutment foundation is set at the proposed bench level of the rock cut slope to minimise risks of instability and erosion in the long term. There is a risk that the rock may be locally more fractured and prone to instability and further assessment of these risks and any construction inspection/remediation requirements would be required at detailed design stage. Also see specific hazard and risk items 18, 31, & 41 in Appendix I of this GIR.
CH 2+690	Gloucestershire Way crossing	Based on the geological plans and the ground investigation information available, the structure is anticipated to be underlain by Salperton and Aston Limestone Formations, and potentially the upper sections of the Birdlip Limestone Formation, all of the Inferior Oolite Group. The proposed road is in cutting at the structure location. The foundations for the east abutment, the east wing walls and the intermediate piers are anticipated to be sitting on competent limestone rock, which is assumed to be suitable for a spread foundation solution. The west abutment and wing walls are anticipated to be formed using contiguous bored piles to allow flexibility in the abutment position (to minimise deck length), facilitate construction and minimise risks of localised instability (given the position within the cutting slope). The piles are anticipated to be formed through weak to medium strong variably fractured limestone of the Inferior Oolite Group. The form and foundation of the abutments and wing walls would need to be reviewed at the detailed design stage (e.g. the contiguous pile wall solution for the west wing walls) in light of further ground investigation information that becomes available and the development of design/construction proposals (including interface with the cutting excavations). Also see specific hazard and risk items 18, 31, in Appendix I of this GIR.
CH 3+200	Shab Hill junction underbridge	The majority of the proposed structure area is expected to be underlain by the Fuller's Earth Formation. The Salperton Formation of the Inferior Oolite Group underlies the Fuller's Earth. A new fault (named the Churn Valley Fault) has been identified which appears to cross the north-east

Chainage	Structure	Foundation type and considerations
		part of the proposed bridge area, and it is hence possible that the structure may be partially underlain directly by the limestones of the Salperton Formation. Given the variability of the ground conditions in the vicinity of the bridge, It has been recommended at this stage allowance be made for the abutments and the wing walls to be supported on bored piles penetrating throughout the Fuller's Earth Formation and socketed into the underlying Inferior Oolite Group limestone. The feasibility of shallow foundations to support both the abutments and wing walls would be assessed during the detailed design stage, in the light of any additional ground investigation information that becomes available and the development of design/construction proposals (including interface with the embankment/junction earthworks and potential ground improvement works). Also see specific hazard and risk items 8, 18 & 42 in Appendix I of this GIR.
CH 4+040	Cowley overbridge	Based on the geological plans and the limited ground investigation information the proposed structure is anticipated to be underlain by the Fuller's Earth Formation potentially with a limited cover of overlying Great Oolite limestone. Given the limited ground investigation available and the uncertainties about the ground conditions across the site, the abutments and the wing walls are anticipated to be supported on bored piles penetrating through the Fuller's Earth Formation and socketed in the underlying Inferior Oolite Group limestone, which is anticipated to be some 15-20m below the proposed carriageway level at the bridge location. The abutment and wingwall foundation solutions would be reviewed at the detailed design stage (e.g. shallow foundations may be suitable to support the wing walls), in the light of the additional ground investigation proposed and the development of design/construction proposals (including interface with the embankment earthworks and remedial works). Also see specific hazard and risk items 18 & 43 in Appendix I of this GIR.
CH 4+735	Stockwell overbridge	The geological plans show the proposed structure area to be underlain by Great Oolite Group limestone over, in turn, Fuller's Earth Formation and Inferior Oolite Group limestone, and the Stockwell Fault approximately 60m to the south of the structure. However, the interpretation of the ground investigation information (including exploratory holes and geophysical surveys) indicates the Stockwell Fault to run across the proposed structure location. The GI information indicates the Fuller's Earth Formation to be present from surface across the full footprint of the bridge, albeit there may be a significant step in the depth to the base of the Fuller's Earth beneath the footprint of the bridge due to the presence of the fault. Given the uncertainties about the ground conditions across the site due to the interpreted new alignment of the Stockwell fault, the abutments and the wing walls are anticipated to be supported on bored piles penetrating throughout the Fuller's Earth Formation and socketed into

Chainage	Structure	Foundation type and considerations
		the underlying Salperton Limestone Formation of the Inferior Oolite Group. The abutment and wing-wall foundation solution would be reviewed at the detailed design stage (e.g. shallow foundations may be suitable to support the wing walls), in the light of the additional ground investigation proposed and the development of design/construction proposals (including interface with the embankment earthworks and remedial works). Also see specific hazard and risk items 8 & 18 in Appendix I of this GIR.

Abbreviations List

ACEC	Aggressive Chemical Environment for Concrete
ACM	Asbestos containing material
ANOB	Area of Outstanding Natural Beauty
AS	Total sulfate content
BDS	Bridport Sand Formation
BGS	British Geological Survey
BRE SD	Building Research Establishment Special Digest
c’	Drained cohesion
c’peak	Drained cohesion (peak)
c’residual	Drained cohesion (residual)
CBR	California Bearing Ratio
Ch	Chainage
CO2	Carbon dioxide
CP	Cable percussion borehole
CPT	Cone penetration test
CSG	Cheltenham Sands and Gravels
CSM	Conceptual site model
cu	Undrained shear strength
CUT	Consolidated undrained triaxial test
DCO	Development consent order
DfT	Department of Transport
DMRB	Design Manual for Roads and Bridges
DQRA	Detailed quantitative risk assessment
DS	Design Sulfate
DSRC	Dynamic sampler with rotary follow on borehole
DTM	Digital terrain model
E’	Drained Young’s Modulus
EA	Environment Agency
EM	Electromagnetic (surface geophysical mapping)
Em	Rock mass stiffness
ERT	Electrical resistivity tomography (surface geophysical mapping)

ES	Environmental Statement
ESG	European Geophysical Services Limited
Eu	Undrained Young's Modulus
f'cv	Constant volume angle of shearing resistance
f'peak	Peak angle of shearing resistance
f'residual or r	Residual angle of shearing resistance
FEF	Fuller's Earth Formation
GEL	Geotechnical Engineering Limited
GI	Ground investigation
GIR	Ground Investigation Report
GOG	Great Oolite Group
GSI	Geological strength index
GWS	Groundwater soluble sulfate
IOG	Inferior Oolite Group
LiDAR	Light detection and ranging (remote sensing)
m AOD	metres above ordnance datum
m bgl	metres below ground level
MASW	Multichannel analysis of surface waves (surface geophysical mapping)
MCV	Moisture condition value
MMD	Mass movement deposit
MMP	Materials management plan
mv	Coefficient of volume compressibility
OH	Open hole rotary borehole
OMC	Optimum moisture content
PAH	Poly aromatic hydrocarbon
PI	Plasticity index
PLI	Point load index
PRA	Preliminary risk assessment
PSD	Particle size distribution
PSSR	Preliminary Sources Study Report
RC	Rotary core borehole
RQD	Rock quality designation
SPT	Standard penetration test

SPT N60	SPT N value corrected to 60% of the theoretical free-fall hammer energy
TP	Trial pit
TPS	Total potential sulfate
TS	Total sulphur
UCS	Unconfined compressive strength
UT100	Undisturbed thin walled 100mm sample
UU	Unconsolidated undrained triaxial test
WAC	Waste acceptance criteria
WS	Water soluble sulfate

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Appendices

Table of Contents

Appendix A Site visit records

A.1 Introduction

A.1.1.1 This appendix presents the records from several site visits carried out by the Arup ground engineering team. This includes the observations made during geological and geomorphological mapping, rock mass assessments and detailed stratigraphical observations.

A.1.1.2 This appendix presents the factual information collected. Appendix B describes how this information has been used to develop the geological plan and ground model.

A.2 Historical records

A.2.1.1 Historical site visits have been undertaken in the study area and the surrounding landscape as part of the previous optioneering studies for the improvement of the A417. The historical records are presented within the PSSR.

A.3 Arup site visits

A.3.1.1 To supplement the existing mapping sources and ground investigation data, several site visits were carried out, with slightly different aims. This includes the following:

- **Scheme wide general site visit – 7 and 8 August 2019**: General site visit with various members of the ground engineering team to carry out geological and geomorphological mapping and a review presence and extent of hydrogeological features such as springs.
- **General site visit at Crickley Hill and Shab Hill – 29 August 2019**: General site visit with geotechnical design members of the ground engineering team.
- **Rock mass characterisation site visit at Crickley Hill and Stockwell** – **10 October 2019**: Targeted site visit to four key exposures of Inferior Oolite Group and Great Oolite Group to undertake rock mass characterisation.
- **Natural England site visit at Crickley Hill – 7 November 2019:** Targeted site visit with Natural England geologist to view exposures of the Leckhampton Member of the Inferior Oolite Formation.

A.3.1.2 The findings of the historical and current geological mapping are summarised in Appendix B and location references are presented within the geotechnical site walkover location plans (HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000018; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000019) presented in Appendix J.

A.3.2 Scheme wide general site visit – 7 and 8 August 2019

A.3.2.1 A site visit was undertaken on 7 and 8 August 2019. The site visit team included two engineering geologists, two geotechnical engineers and a hydrogeologist. The purpose of this trip was to have a general walkover to collect information on the following:

- Observation and recording of geological exposures to inform geological mapping.

- Where possible, take measurements of the bedrock structure to inform geological mapping.
- Observation and recording of geomorphological features to inform the understanding of the conceptual slope process models for the Cotswold escarpment and Churn Valley.
- Observation and recording of any other features such as vegetation changes, hydrological and hydrogeological features and more general geomorphological features to inform the geological mapping.
- Observation and recording of hydrogeological features to inform the understanding of the conceptual hydrogeological model.

A.3.2.2 The location of observations made during the Arup site visit on 7 and 8 August 2019 are presented in drawings HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000018; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000019 presented in Appendix J, and summarised within Table A-1. Record photographs are included in Table A-2.

Table A-1 Summary of observations made during the Arup site visit carried out on 7 and 8 August 2019. See Table A-2 for record photographs.

Ref	Easting	Northing	Location	Observation[1]	Photo reference (see Table A-2)
1	393272	215734	Barrow Wake	Steep gully in dense woodland off Cotswold way.	IMG_9526 Photograph 1
2	393214	215727	Barrow Wake	Depression – (Potential sinkhole or Quarry).	IMG_9527 Photograph 2
3	393179	215751	Barrow Wake	Ooidal limestone (IO) exposure 026/06/E.	IMG_9528 Photograph 3 IMG_9629 Photograph 4
4	393051	215702	Barrow Wake	Spring flowing outside Grove Farm.	IMG_9530 Photograph 5
5	393078	215762	Barrow Wake	Slopes below Barrow Wake Car Park, looking SW.	IMG_3237 Photograph 6
6	393076	215662	Barrow Wake	Slopes below Barrow Wake Car Park, looking SE.	IMG_3240 Photograph 7
7	393112	215534	Barrow Wake	1.5m x 1.0m limestone (IO) boulder fallen from exposure below car park.	IMG_3244 Photograph 8
8	393127	215478	Barrow Wake	Scree slope in line with source of boulder, coarse gravel sized limestone (IO) fragments up to 500mm (in all dimensions).	IMG_3248 Photograph 9 IMG_3245 Photograph 10
9	393147	215481	Barrow Wake	Massive limestone (IO) exposure. Rubbly appearance with evidence of fresh rock fall.	IMG_3253 Photograph 11 IMG_3255 Photograph 12
10	393150	215461	Barrow Wake	Suspected gull, slight infill.	IMG_3259 Photograph 13 IMG_3262 Photograph 14
11	394172	214273	Stockwell / Cowley	Great Oolite exposure, thickly bedded ~200mm, jointed, 162/12/SE.	IMG_3264 Photograph 15

Ref	Easting	Northing	Location	Observation[1]	Photo reference (see Table A-2)
12	394258	214183	Stockwell / Cowley	Fly tipped materials	IMG_3265 Photograph 16
13	394319	214135	Stockwell / Cowley	Potential surface expression of the Stockwell Fault. Flat valley depression parallel to footpath.	IMG_3266 Photograph 17
14	394372	214102	Stockwell / Cowley	View looking S, small landslips on hillside and flat-bottomed dry valley.	IMG_3267 Photograph 18
15	394505	213932	Stockwell / Cowley	Valley feature confirmed from WSP mapping.	IMG_3269 Photograph 19
16	394551	213984	Stockwell / Cowley	Photo looking S: Potential surface expression of the Stockwell Fault. E-W depression; Photo looking SE: southern side of proposed Cowley overbridge in FEF.	IMG_3278 Photograph 20
17	394718	213936	Stockwell / Cowley	Proposed overbridge abutment location, looking south, hummocky ground in FEF.	IMG_3280 Photograph 21
18	394505	214763	Stockwell / Cowley	Waterlogged ground where spring was mapped on 1:10,560 map.	IMG_3283 Photograph 22
19	394848	213896	Stockwell / Cowley	Poor quality soil conditions in gently undulating topography. Interpreted to be FEF outcrop.	IMG_3285 Photograph 23
20	394888	213807	Stockwell / Cowley	Poor quality soil conditions in gently undulating topography. Interpreted to be FEF outcrop. In distance the topography drops away to form a shallow valley.	IMG_3289 Photograph 24
21	394792	213954	Stockwell / Cowley	View across plateau from Stockwell area. Topography is generally level with shallow dry valleys.	IMG_3298 Photograph 25
22	394593	214410	Stockwell / Cowley	View across plateau towards Stockwell Farm. Topography generally level.	IMG_3300 Photograph 26
23	394389	214556	Stockwell / Cowley	View across plateau from Stockwell area. Topography slopes gently towards NE.	IMG_3304 Photograph 27
24	394504	214757	Edge of Churn Valley	Overgrown and marshy area in corner of field. Photo looking 220°.	IMG_3306 Photograph 28
25	394558	215043	Edge of Churn Valley	View of Churn Valley from south side of valley. Gently undulating topography with steep valley sides (interpreted to be limestone outcrop of IO).	IMG_3307 Photograph 29
26	394311	214938	Edge of Churn Valley	Photograph of small quarries on the edge of Churn Valley.	IMG_3309 Photograph 30
27	394178	214952	Edge of Churn Valley	Break in slope within cropped field indicating boundary between FEF and underlying IO.	IMG_3312 Photograph 31
28	394185	214954	Edge of Churn Valley	Clasts of IO in field.	IMG_3313 Photograph 32
29	393196	216044	Crickley Hill	Benched cutting within IO towards the top of the escarpment.	IMG_3320 Photograph 33

Ref	Easting	Northing	Location	Observation[1]	Photo reference (see Table A-2)
30	393196	216044	Crickley Hill	Limestone exposure, oncoids, scree slope (Suspected exposure of the 'Pea Grit' of the Crickley Formation of IO)	IMG_3327 Photograph 34 IMG_3326 Photograph 35
31	393184	216037	Crickley Hill	Remnants of rock mesh on benched cutting in IO.	IMG_3333 Photograph 36
32	393118	215993	Crickley Hill	Waterlogged muddy ground adjacent to A417. Water appears to be coming from a spring and forming a headwater.	IMG_3343 Photograph 37
33	393110	215994	Crickley Hill	Drainpipe on slope (dry); spring below it approx. 216mOD	IMG_3358 Photograph 38
34	393127	216015	Crickley Hill	Limestone exposure (Suspected to be the Scissum Beds of IO)	IMG_3349 Photograph 39
35	393143	216015	Crickley Hill	0.5m x 0.5m boulder on slope.	IMG_3351 Photograph 40
36	393140	216027	Crickley Hill	Limestone (IO) exposure upslope from boulder, 067/20/S	IMG_3353 Photograph 41
37	393071	215961	Crickley Hill	Counterfort drains in hillside. Drain is gravel filled and approximately 3.5 to 4m wide	IMG_3358 Photograph 42
38	393025	215950	Crickley Hill	Backwards and forwards rotated trees	IMG_3363 Photograph 43
39	392957	215918	Crickley Hill	Backwards and forwards rotated trees	IMG_3377 Photograph 44
40	392995	215949	Crickley Hill	Small landslide backscarp and toe.	IMG_3369 Photograph 45
41	392978	215879	Crickley Hill	Spring 1 flowing into drain; spring 2 under stone wall.	IMG_3384 Photograph 46
42	392461	215781	Crickley Hill	Hummocky ground on hillslope.	IMG_3394 Photograph 47
43	392402	216118	Crickley Hill	Cambered block of IO on top of Crickley Hill.	IMG_3397 Photograph 48
44	392798	216290	Crickley Hill	Scree slope on north side of Crickley Hill	IMG_3399 Photograph 49
45	392816	216275	Crickley Hill	Exposure of Inferior Oolite with varying rock mass characteristics.	IMG_3410 Photograph 50
46	393868	215189	Shab Hill	Exposure of Great Oolite Group (GOG) within old quarry within the Churn Valley slope. Rock structure: 109/05/S.	IMG_3426 Photograph 51
47	394018	215269	Shab Hill	View of western extent of Churn Valley where the valley slope geomorphology abruptly changes from regular to more irregular.	IMG_3437 Photograph 52
48	393916	215241	Shab Hill	Landslide within the Fuller's Earth outcrop.	IMG_3432 Photograph 53
49	394149	215212	Shab Hill	Cambered south side slope of Churn Valley. Several small rotational landslides and evidence of solifluction within the Fuller's Earth outcrop.	IMG_3453 Photograph 54
50	394282	215096	Shab Hill	Landslip in Fuller's Earth	IMG_3447 Photograph 55

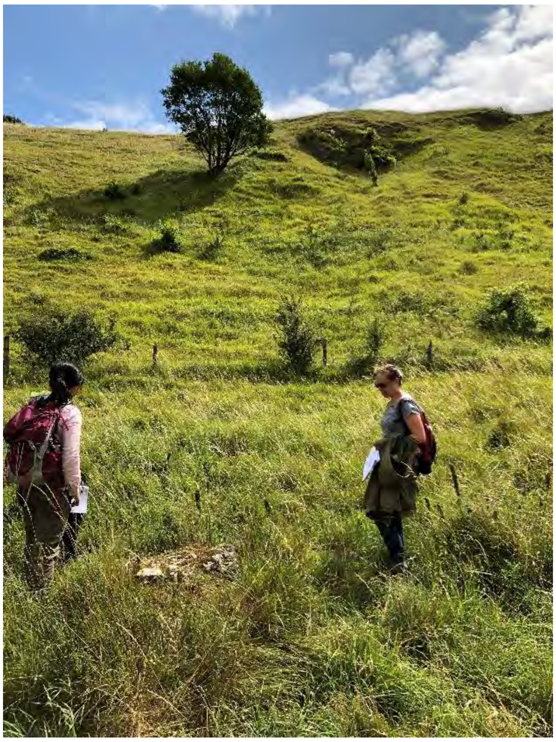
Ref	Easting	Northing	Location	Observation[1]	Photo reference (see Table A-2)
51	393961	215275	Shab Hill	View of Churn Valley dry riverbed.	IMG_3434 Photograph 56

Notes
1) Measurements of bedding or discontinuities are presented in the following format: strike/dip angle/direction.

Table A-2 Record photographs from the Arup site visit carried out on 7 and 8 August 2019.

Photograph 1	Photograph 2
Photograph 1: IMG_9526. Photograph of a steep gully in dense woodland off Cotswold Way. Photo looking 290º. 	Photograph 2: IMG_9527. Photograph of depression within woodland. Possible sinkhole or quarry. Landscape appears artificial. Photo looking 290º 

Photograph 3: IMG_9528. Photograph of Inferior Oolite exposure. Exposure appears artificial and has likely been quarried. Photo looking 200º. 	Photograph 4: IMG_9529. Photograph of sample of Inferior Oolite. Noted to be primarily ooidal with whole shelly fossils. Photo looking 200º. 
Photograph 5: IMG_9530. Photograph spring flowing outside of Grove Farm. Photo looking 180º. 	Photograph 6: IMG_3237. Photograph of the escarpment slopes below Barrow Wake. Photo looking 220º 

Photograph 7: IMG_3240. Photograph of the escarpment slope below Barrow Wake Car Park. Photo looking 160º. 	Photograph 8: IMG_3244. Photograph of 1.5m x 1.0m limestone (IO) boulder fallen from exposure below car park. Photo looking 120º. 
Photograph 9: IMG_3248. Photograph of scree slope in line with source of boulder, coarse gravel sized limestone (IO) fragments up to 500mm long cobbles. Photo looking 020º. 	Photograph 10: IMG_3245. Photograph of scree slope in line with source of boulder. 

<table>
<tr>
<td>Photograph 11: IMG_3253. Photograph of limestone (IO) exposure on escarpment slope. Photo looking 100º.
</td>
<td>Photograph 12: IMG_3255. Photograph of fresh rockfall scar from limestone (IO) exposure. Photo looking 100º.
</td>
</tr>
<tr>
<td>Photograph 13: IMG_3259. Photograph of small (circa 100-300mm wide) gull fissure within limestone (IO) exposure on escarpment slope. Photo looking 020º.
</td>
<td>Photograph 14: IMG_3262. Photograph of limestone (IO) exposures with gull fissures on escarpment slope. Photo looking 020º.
</td>
</tr>
</table>

Photograph 15: IMG_3264. Photograph of bedded limestone (interpreted to be GOG). Circa 200mm spacing between beds. Bedding structure 12/162 SE. Photo looking 040º.

Photograph 16: IMG_3265. Photograph of fly tipped material at Stockwell Farm. Photo looking 170º.

Photograph 17: IMG_3266. Photograph of a flat dry valley base. Flat valley depression parallel to footpath. Photo looking 140º.

Photograph 18: IMG_3267. Photograph of small shallow landslides on the side slopes of Stockwell valley. Valley has a distinct flat bottom and is dry. Photo looking 220º.

Photograph 19: IMG_3269. Valley feature identified by WSP mapping. Photo looking 270º. 	Photograph 20: IMG_3278. Photograph looking S: Stockwell Fault? E-W depression. Southern side of proposed Cowley overbridge. In Fuller's Earth. Photo looking 100º. 
Photograph 21: IMG_3280. Proposed overbridge abutment location, looking south, hummocky ground in Fuller's Earth. Photo looking 240º. 	Photograph 22: IMG_3283. Photograph of waterlogged ground where spring is mapped on 1:10,560 geology map. Photo looking 280º. 

Photograph 23: IMG_3285. Poor quality soil conditions in gently undulating topography. Interpreted to be Fuller's Earth outcrop. Photo looking 200º. 	Photograph 24: IMG_3289. Poor quality soil conditions in gently undulating topography. Interpreted to be Fuller's Earth outcrop. In distance the topography drops away to form a shallow valley. Photo looking 090º. 
Photograph 25: IMG_3298. View across plateau from Stockwell area. Topography is generally level with shallow dry valleys. Photo looking 320º. 	Photograph 26: IMG_3300. View across plateau towards Stockwell Farm. Topography generally level. Photo looking 220º. 

Photograph 27: IMG_3304. View across plateau from Stockwell area. Photo looking 300º.

Photograph 28: IMG_3306. Overgrown and marshy area in corner of field. Photo looking 220º.

Photograph 29: IMG_3307. View of Churn Valley from south side of valley. Gently undulating topography (interpreted to be limestone outcrop – IO). Dry valley in foreground. Photo looking 050º.

Photograph 30: IMG_3309. Photograph of small quarries on the edge of Churn Valley. Photo looking 90º.

Photograph 31: IMG_3312. Break of slope within arable field. Interpreted to represent the boundary between the FEF and underlying IO. View looking 220 º.

Photograph 32: IMG_3313. Photograph of clasts of IO within ploughed arable field. Photo looking 180º.

Photograph 33: IMG_3320. Photograph of benched cutting within IO towards the top of the escarpment. View looking 80 º.

Photograph 34: IMG_3327. Photograph of limestone exposure, oncoids, scree slope (Pea Grit of the IO). Photo looking 340º.

Photograph 35: IMG_3326. Photograph of limestone exposure, oncoids, scree slope (Pea Grit of the IO). Photo looking 340º. 	Photograph 36: IMG_3333. Photograph of remnants of wire mesh on benched cutting in IO. Photo looking 270º. 
Photograph 37: IMG_3326. Photograph of waterlogged and muddy ground. Water appears to be coming from a spring and forming a headwater. Photo looking 090º. 	Photograph 38: IMG_3358. Photograph of spring emerging from drainpipe in rock slope. Rock slope is likely to have been benched but look fairly irregular. Photo looking 120º. 

Photograph 39: IMG_3349. Photograph of possible Scissium Beds within the Leckhampton Member of the Inferior Oolite. This member marks the boundary between the IO and the underlying Bridport Sand Formation (Lias Group). Photo looking 350º. 	Photograph 40: IMG_3351. Photograph of boulder that had fallen towards the existing A417 from an exposure of IO. Photo looking 045º. 
Photograph 41: IMG_3353. Photograph of limestone (IO) exposure upslope from boulder in Photograph 40. Rock structure 067/20/S. Photo looking 350º. 	Photograph 42: IMG_3358. Photograph of counterfort drain in hillside. Drain is gravel filled and approximately 3.5 to 4m wide. Photo looking 350º. 

Photograph 43: IMG_3363. Photograph of forward and backwards leaning trees within hillslope. Photo looking 350º.	Photograph 44: IMG_3377. Photograph of forward and backwards leaning trees within hillslope. Photo looking 250º.
	

Photograph 45: IMG_3369. Photograph of backscarp and toe of small landslide with forwards leaning tree. Photo looking 045º.

Photograph 46: IMG_3384. Spring 1 flowing into drain; spring 2 under stone wall. Photo looking 350º.

Photograph 47: IMG_3394. Hummocky ground on hillslope (difficult to see in photo due to heavy vegetation). Photo looking 300º.

Photograph 48: IMG_3397. Cambered block of IO. Photo looking 240º.

Photograph 49: IMG_3399. Scree slope of north side of Crickley Hill. Photo looking 160º.

Photograph 50: IMG_3410. Photograph of an exposure of IO on the northern side of Crickley Hill. The exposure shows the rubbly nature of the pea grit (pale orangish brown surface) at the base of the exposure. Compared to the overhanging bedded limestone (IO) above. Photo looking 150º.

Photograph 51: IMG_3426. Exposure of Great Oolite Group (GOG) within old quarry on Churn Valley slope. Photo looking 160º.

Photograph 52: IMG_3437. View of western extent of Churn Valley where the valley slope geomorphology abruptly changes from regular to more irregular, which is interpreted to represent the Churn Valley fault. Photo looking 220º.

Photograph 53: IMG_3432. Photograph of a landslide within the Fuller's Earth outcrop. Photo looking 180º.

Photograph 54: IMG_3453. Cambered south side slope of Churn Valley. Several small rotational landslides and evidence of solifluction within the Fuller's Earth outcrop. Photo looking 150º. 	Photograph 55: IMG_3447. Landslide in Fuller's Earth. Photo looking 300º. 
Photograph 56: IMG_3397. View of Churn Valley dry riverbed. Photo looking 110º. 	

A.3.3 Rock mass characterisation site visit at Crickley Hill and Stockwell – 10 October 2019

A.3.3.1 A site visit was undertaken on 10 October 2019. The site visit team included four engineering geologists. The purpose of this trip was to carry out rock mass characteristic assessments of exposures of the Inferior Oolite Group and Great Oolite Group. Another aim of this site visit was to collect information on the boundary between the Inferior Oolite and Lias Group.

A.3.3.2 Thickly- and medium-bedded oolitic and bioclastic limestones, interpreted to be part of the Birdlip Limestone Formation (IOG) were examined at three localities (Exposure 1, 2, 3), as summarised Table A-3 and locations presented within the geotechnical site walkover location plans (HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000018; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000019) presented in Appendix J.

A.3.3.3 An exposure of Great Oolite Group was examined at a single location (Exposure 4), as summarised within Table A-3 and location presented within the geotechnical site walkover location plans (HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000018; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000019) presented in Appendix J.

A.3.3.4 To inform rock mass assessments a scan line survey was undertaken at Exposures 2, 3 and 4. Exposure 1 was unsafe to access and carry out a detailed examination. The surveys recorded dip and dip direction, spacing, roughness, aperture, persistence, infill and water content. The full results of scan line surveys are attached to this appendix.

A.3.3.5 The location references from the Arup site visit on 10 October 2019 are presented on drawings HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000018; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000019 in Appendix J, and summarised within Table A-4. Record photographs are included in Table A-5 and the below text.

Table A-3 Summary of exposure locations visited during the site walkover on 10 October 2019

Locality	Easting	Northing	Approx. elevation (mAOD)	Strata	Observations
Crickley Hill North Exposure 1	392966	216333	260	Inferior Oolite Group	Former quarry. Extremely wide infilled vertical void/gull, that is perpendicular to bedding. Infilled with reddish brown soil (lithology unknown, interpreted as Head) interbedded with brecciated, thinly bedded, weathered limestone. Weathered limestone dips into infilled gull. Base not seen.
Crickley Hill North Exposure 2	392835	216307	229	Inferior Oolite Group	Former quarry. Multiple open voids and joints, parallel and oblique to bedding within interbedded, thinly- and medium bedded limestone and thinly- to very-thinly bedded sandy silt. Limestone is bridged over open voids with sub-vertical beds. The sequence at this locality is dominated by rubbly and blocky limestone beds, which run continuously sub-horizontally across the

Locality	Easting	Northing	Approx. elevation (mAOD)	Strata	Observations
					outcrop. The limestone beds are medium- to thick-bedded (200mm to more than 600mm) and are interbedded with >20mm beds of orange-red sandy material. The rock mass is tabular and slightly weathered. The limestone beds coarsen upwards through the outcrop into uniformly very coarse, flattened or elongate peloid grains with little to no supporting matrix. These peloid grains are present throughout the upper beds, as seen in fresh rock surfaces. Whole shells can be identified in these upper beds, compared to tiny (2mm) shell fragments identified lower down the outcrop. The lower beds show more characteristics of matrix-supported packstones with a calcite cement. This section of flattened peloids is interpreted to be the 'Pea Grit' or Crickley Member. Open voids and discontinuities with a spacing of 600mm to 2m were observed in this outcrop. The discontinuity aperture was measured to be mostly wide (>200mm). The voids extended both face-parallel and into the rock surface. The joints climb both up and across bedding. Evidence of collapsed voids is present in the form of irregular discontinuity surfaces. The nature of fracture infilling was either clean or cemented. A potential fault (in Photograph 73 bi and bii) was identified to the left of the outcrop illustrated in Photograph 74. This 'fault' was interpreted to be downthrown to the east by less than 5m and could be an extension of the Shab Hill Fault zone. Around the fault the limestone bedding is seen to have been locally rotated from typically sub-horizontal bedding of the regional geology to sub-vertical. It is unclear if the deformation is caused by collapse into an underlying void, cambering processes or is fault related. This finding has engineering significance because it is a zone of deformed and more heavily fractured rock mass with potential for open voids and discontinuities. At Exposures 1, 2 and 3 (in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017), the bedding and jointing discontinuities are overprinted by offset small, curved fractures. An example of these fractures can be seen in Photograph 71 from Exposure 2. These fractures are either face-parallel or extend into the rock face and lie within beds rather than

Locality	Easting	Northing	Approx. elevation (mAOD)	Strata	Observations
					on bedding planes. The suspected cause of these discontinuities is frost-weathering.
Crickley Hill South Exposure 3	392961	215983	217	Inferior Oolite Group	Former quarry. Medium-bedded limestone grading upwards into weathered, thinly bedded limestone. Limestone beds separated by thickly laminated sandy silt. Medium-bedded limestone blocks bridge open voids. Potential gull infilled with talus. The Birdlip Limestone Formation outcrop seen on the south facing side of Crickley Hill (Exposure 3 in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017) is presented in Photograph 75. Due to the approx. 12m difference in elevation, this exposure was expected to be further down the succession of the Birdlip Limestone sequence, compared to Exposure 1. This exposure appeared to be higher in the succession and is anticipated to be the result of cambering of the limestone. The Birdlip Limestone Formation at this locality is formed of more uniform, thicker and more competent limestone beds that thin upwards. It appears to be less weathered than Exposure 2 on the north side of Crickley Hill. The limestone beds are interbedded with thin, fissile sandy beds, similar to those observed at Exposure 1. There are large overhangs throughout the height of the exposure where these sandy less competent beds have been eroded and washed out. The size of the overhangs increases with height. The rock fabric is tabular and slightly weathered. Several joints were identified at this exposure. They had a mostly wide aperture of >200mm, and their nature of infilling was clean. The joints extend perpendicularly into the outcrop face and running parallel behind it. Some of these joints are indicated in Photograph 72 and are shown to terminate at bedding planes. A large, open sub-vertical joint was identified in the western corner of the quarry. This joint has formed a void of 2-3m that separates a large tabular column of rock from the escarpment edge Photograph 62. The separated column is more orange-brown than the cliff face. This is thought to be due to increased weathering of the rock face along surface-parallel joints that form a focal point for water infiltration.

Locality	Easting	Northing	Approx. elevation (mAOD)	Strata	Observations
Stockwell Farm Exposure 4	394172	214272	266	Great Oolite Group	Artificial cutting made into low angle hillslope to form level area for Stockwell Farm. Low height (circa 1-2m) exposure of bedded limestone.

Table A-4 Summary of observations made during the Arup site visit carried out on 10 October 2019. See Table A-5 for record photographs..

Ref	East	North	Location	Observation	Photo reference (see Table A-5)
1	392834	216308	Crickley Hill North Exposure 2	Fault identified at 229m. Fault trace approx. 190°. Downthrown to E <5m. Upper beds dipping into fault plane.	Photograph 57
2	392832	216303	Crickley Hill North Exposure 2	Open voids and massive open sub-vertical joints overprinted by spalling. Spalling controlled by frost weathering.	Photograph 58 Photograph 59
3	392833	216305	Crickley Hill North Exposure 2	Overhanging limestone (IO) beds interbedded with thin sandy beds.	Photograph 60
4	392956	215982	Crickley Hill South Exposure 3	Face-parallel joints 80dip/359dip direction. Open sub-vertical joint max 30mm. Joints pass down and along bedding planes.	Photograph 61
5	392956	215982	Crickley Hill South Exposure 3	Active material gully formed in collapsed joint (width 2-3m).	Photograph 62
6	392961	215983	Crickley Hill South Exposure 3	Base of Pea Grit identified at approx. 220m. Coarsens upwards into chalky pale orangey pink beds.	Photograph 63
7	392960	215983	Crickley Hill South Exposure 3	Hardground identified - irregular wavy band in bed with large shell fragments. Wavy features (possibly ripples) on over hanging base of bed.	Photograph 64
8	392960	215984	Crickley Hill South Exposure 3	Large sub-vertical joints and deep voids. Overhanging limestone (IO) beds. and some dissolution holes.	Photograph 65 Photograph 66
13	394164	214278	Stockwell Exposure 4	Bed of marly fissile siltstone beneath well-sorted limestone (GOG). V-fine grained.	Photograph 67
14	394172	214272	Stockwell Exposure 4	Ooidal GOG limestone. Well sorted. Grain size 1-2mm. Pale pinky-yellow. 150-250mm beds. Vertical & horizontal beds. Dogtooth calcite precipitation along joint planes growing outwards into joints.	Photograph 68

Table A-5 Record photographs from the Arup site visit carried out on 10 October 2019.

Photograph 57: Photograph of fault identified at 229mOD. Strike 193deg. Downthrown to E <5m. Upper beds dipping into fault plane. Photo looking 120º. 	Photograph 58: Photograph of open voids and open joints overprinted by spalling. Spalling controlled by frost weathering. Photo looking 130º. 
Photograph 59: Photograph of open voids and open joints overprinted by spalling. Spalling controlled by frost weathering. Photo looking 130º. 	Photograph 60: Photograph overhanging limestone (IO) beds interbedded with thin sandy beds. Photo looking 130º 

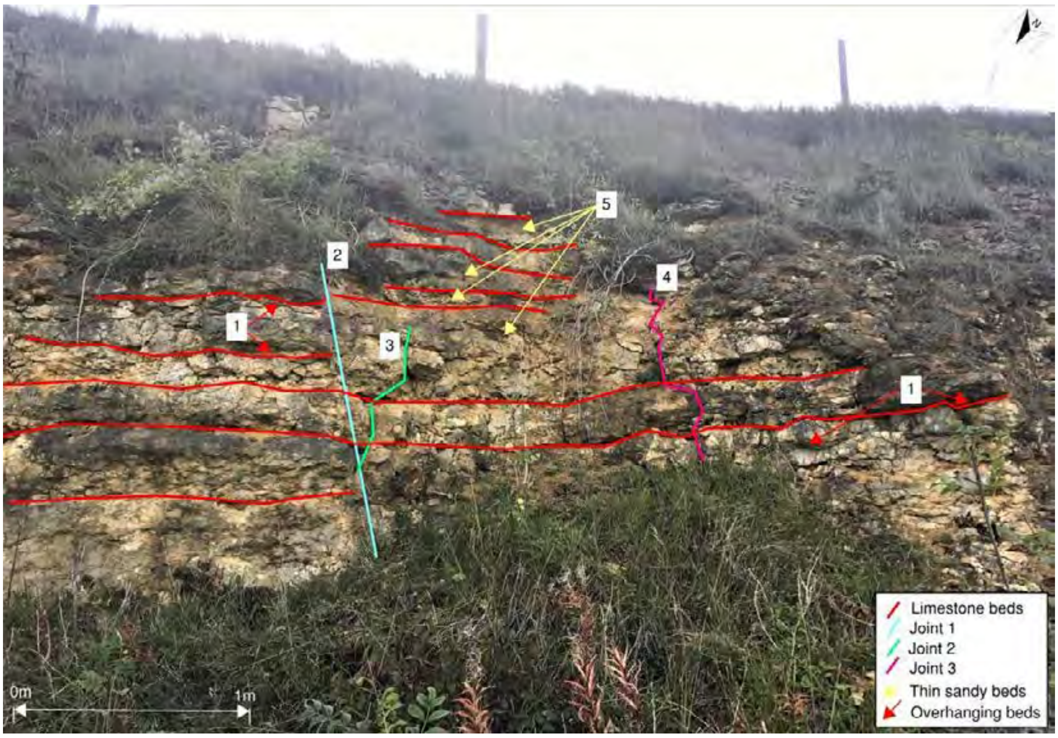
Photograph 61: Photograph of face-parallel joints 80dip/359dip direction. Open sub-vertical joint max 30mm. Joints pass down and along bedding planes. Photo looking 90º. 	

Photograph 62: Photograph of active material gully formed in collapsed joint (width 2-3m). Photo looking 340º

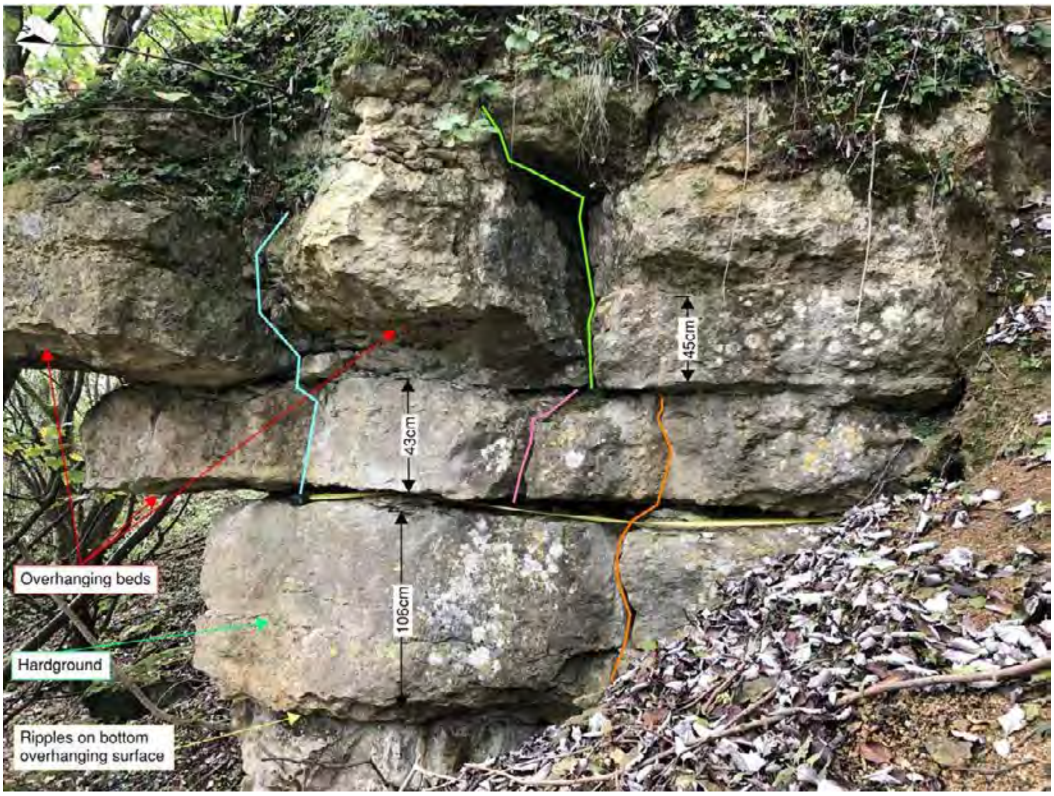
Photograph 63: Photograph of base of Pea Grit identified at approx. 220mOD. Coarsens upwards into chalky pale orangey pink beds. Photo looking 340º. 	Photograph 64: Photograph of hardground with irregular wavy band in bed with large shell fragments. Wavy features (possibly ripples) on over hanging base of bed. Photo looking 300º. 
Photograph 65: Photograph of large sub-vertical joints and deep voids. Overhanging limestone (IO) beds. and some dissolution holes. Photo looking 300º. 	Photograph 66: Photograph of large sub-vertical joints and deep voids. Overhanging limestone (IO) beds. and some dissolution holes. Photo looking 300º. 

Photograph 67: Photograph of bed of marly fissile siltstone beneath well-sorted limestone (GOG). V-fine grained. Photo looking 40º. 	Photograph 68: Photograph of ooidal GOG limestone. Well sorted. Grain size 1-2mm. Pale pinky-yellow. 150-250mm beds. Vertical & horizontal beds. Dogtooth calcite precipitation along joint planes growing outwards into joints. Photo looking 40º. 

Photograph 69: Annotated outcrop of Birdlip Limestone (IO) on the north side of Crickley Hill [392821E 216282N] (Exposure 2 in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017). Overhanging limestone beds; 2) continuous planar joint surface; 3&4) nonplanar and irregular discontinuity surfaces (possibly due to collapse of voided ground); 5) thin orangey fissile sandy layers interbedded with thicker limestone beds.

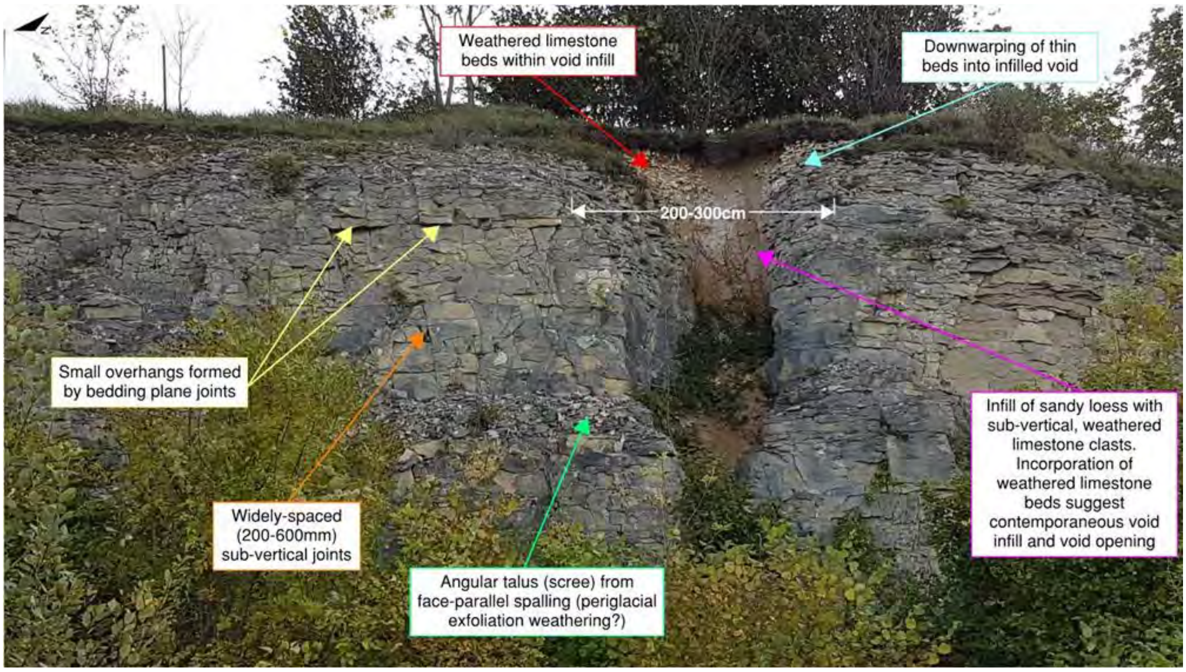


Photograph 70: Annotated outcrop of Birdlip Limestone in a former quarry on the south side of Crickley Hill [392961E 215983N] (Exposure 3 in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017). Green, pink, orange and blue lines indicate sub-vertical joints.

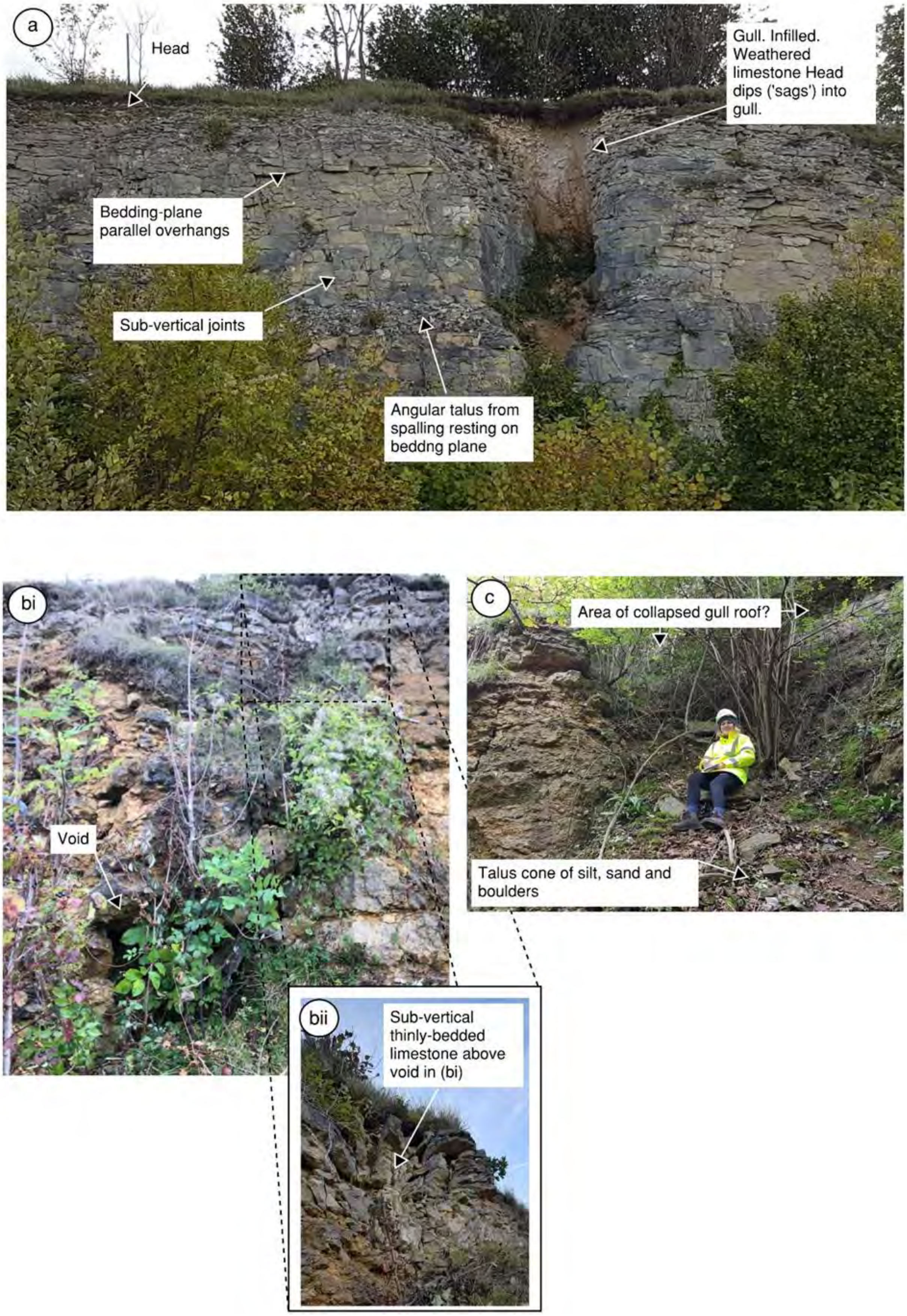


Photograph 71: Potential frost-splitting on Inferior Oolite on the north side of Crickley Hill. Approximate location [SO92844 16304] (Exposure 2 as per HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017). These joints cause spalling and appear to be the source of scree in addition to the bedding plane blocks. Spalling sections easily split by hand pressure. The fractures are extending into the rock face in this example.

Photograph 72: Annotated outcrop of Birdlip Limestone (IO) in a former quarry on the top of Crickley Hill. Approximate location [392964E 216333N] (Exposure 1 as per in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017). Shows accumulation of scree from interpreted face-parallel spalling generated by frost weathering and stress relief.



Photograph 73: Evidence of gulls from site walk over 10th October 2019. a) Crickley Hill, north [392966, 216333], bi) Crickley Hill, north [392835, 216307], bii) close-up of part of bi) and c) Crickley Hill, south [392961, 215983]



A.3.4 Natural England site visit at Crickley Hill – 7 November 2019

A.3.4.1 A site visit was undertaken on 7 November 2019. The site visit team included an Arup engineering geologist and David Evans from Natural England. The purpose of this trip was to discuss the sensitivity of specific existing geological exposures on the slopes of Crickley Hill and identify the boundary between the Lias Group and the overlying Inferior Oolite Group.

A.3.4.2 The location references from the Arup/Natural England site visit on 7 November 2019 are presented on drawings HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000018; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000019 in Appendix J, and summarised within Table A-6. Record photographs are included in Table A-7.

A.3.4.3 The Leckhampton Member (base Member of the Inferior Oolite Formation) was seen in multiple locations on the south facing slope of Crickley Hill to overlie the Bridport Sand Formation. There are occasional discontinuities between these two units, which may indicate the slipping or displacement of blocks in the slope due to cambering.

A.3.4.4 The Leckhampton Member was noted to be present directly adjacent to the existing A417 (see IMG_6790 Photograph 77 and IMG_6786 Photograph 78). This suggests that the base of the Leckhampton Member lies at approximately the level of the road at this point. This indicates that there is likely to be a fault with a downthrow to the east between this point and the exposures further west.

Table A-6 Summary of observations made during the Arup site visit carried out on 7 November 2019. See Table A-7 for record photographs.

Ref	East	North	Location	Observation	Photo reference (see Table A-7)
1	393101	216002	Crickley Hill	Exposure at south west end of transect shows Bridport Sand Formation containing calcareous concretions. Sands saturated towards base. Water flowing freely in shallow gully at base.	IMG_6775 Photograph 74
2	393112	216009	Crickley Hill	Leckhampton Member resting on Bridport Sand Formation. Discontinuity at the eastern end of the section may indicate that this is a slipped/displaced block.	IMG_6777 Photograph 75
3	393109	216005	Crickley Hill	Exposures above first bench. Bridport Sand Formation partially exposed in lower part of face, largely covered in talus and vegetation. Base of Leckhampton Member clearly visible along eastern part of bench, but there appears to be a discontinuity towards the western which could be interpreted either as a fault, or as evidence of cambering. Evidence that there is some downslope creep/ rotation on these slopes may be seen in the curvature of the tree trunks.	IMG_6769 Photograph 76
4	393152	216014	Crickley Hill	Exposure immediately behind road sign shows the Leckhampton Member underlain by a grey mudstone, suggesting (if the mudstone belongs to the Bridport Sand? /Whitby Mudstone? Formation), that the base of the Leckhampton Member lies at about the level of the road at this	IMG_6790 Photograph 77 IMG_6786 Photograph 78

Ref	East	North	Location	Observation	Photo reference (see Table A-7)
				point. If this is the case, then there is likely to be a fault with a downthrow to the east between this point and the exposures further west, as the apparent dip of the exposures to the west would suggest that the junction ought to intersect at road level further east than this point. The intervening area is heavily vegetated, so that it is not possible to determine the distribution of the outcrop between these points. The face of the bench to the east is completely obscured by vegetation.	

Table A-7 Record photographs from the Arup site visit carried out on 7 November 2019.

Photograph 74: IMG_6775. Exposure at south west end of transect shows Bridport Sand Formation containing calcareous concretions. Sands saturated towards base. Water flowing freely in shallow gully at base. Photo looking 10º. 	Photograph 75: IMG_6777. Leckhampton Member resting on Bridport Sand Formation. Discontinuity at the eastern end of the section (right side of photo) may indicate that this is a slipped/displaced block. Photo looking 10º. 
Photograph 76: IMG_6769. Bridport Sand Formation partially exposed in lower part of face, largely covered in talus and vegetation. Base of Leckhampton Member clearly visible along eastern part of bench, but there appears to be a discontinuity towards the western which could be interpreted either as a fault, or as evidence of cambering. Photo looking 45º.	Photograph 77: IMG_6790. Exposure immediately behind road sign shows the Leckhampton Member underlain by a grey mudstone. Photo looking 20º.

Photograph 78: IMG_6786. Exposure immediately behind road sign shows the Leckhampton Member underlain by a grey mudstone, suggesting (if the mudstone belongs to the Bridport Sand? /Whitby Mudstone? Formation), that the base of the Leckhampton Member lies at about the level of the road at this point. If this is the case, then there is likely to be a fault with a downthrow to the east between this point and the exposures further west, as the apparent dip of the exposures to the west would suggest that the junction ought to intersect at road level further east than this point. The intervening area is heavily vegetated, so that it is not possible to determine the distribution of the outcrop between these points. The face of the bench to the east is completely obscured by vegetation. Photo looking 10º.

A.4 Geomorphology

A.4.1 Terrain analysis – Crickley Hill

A.4.1.1 The key findings of the geomorphological analysis using the DTM are presented below and within drawings HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000001 to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000005 in Appendix J.

A.4.1.2 The terrain analysis was carried out to select slope zones within Crickley Hill that could then be used as hazard zones in the slope stability risk assessment. The hazard zones were defined by producing a catchment flow model, which identified the hydrological catchments within the slopes. These catchments were then separated further into relevant sub-catchments according to the slope character (i.e. slope angle, slope aspect), land use, site history and slope hazard types

A.4.1.3 The term Slope Hazard Zone has been used below to ensure consistency within the GIR and subsequent Appendices.

Slope Hazard Zone 1

A.4.1.4 The key geomorphological observations informing the slope hazard assessment in Slope Hazard Zone 1 (See HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000014 in Appendix J) include the following:

- Presence of existing benched cuttings within the Inferior Oolite Formation.
- Accumulation of loose scree behind chain link mesh pegged onto a section of exposed limestone (IO).

Slope Hazard Zone 2

A.4.1.5 The key geomorphological observations informing the slope hazard assessment in Slope Hazard Zone 2 (See HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000005 in Appendix J) include the following:

- Accumulation of Inferior Oolite debris on the lower slopes and artificial benches suggests that the Inferior Oolite Outcrop is the source of rockfall, as well as from the artificially over steepened exposures of the Leckhampton Member and underlying exposed Bridport Sand (Lias Group).
- Rotational landslides with fresh back scars identified above the level of the Marlstone Rock Formation, Hutchinson (1991).
- Cambering inferred from the observed presence of gulls within exposures of Inferior Oolite Formation.
- Slip surfaces, concave breaks in slope and back scarps identified on site visits, associated with tilted trees.
- Evidence of tilted, banking and bent trees identified during site visits on artificially steepened slopes and natural slopes on north side of A417.

Slope Hazard Zone 3

A.4.1.6 The key observations informing the hazard assessment in Slope Hazard Zone 3 (refer to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000004 in Appendix J are:

- Multiple geomorphological features associated with landsliding identified on through analysis of the DTM, including:
  - Concave breaks in slope
  - Back scarps (often aligned with springs)
  - Landslide toes
- Multiple small, shallow slips accumulating on engineered artificially steepened slopes.
- Tilted trees identified on Google street view close to existing mainline, suggesting relatively recent movement.
- Large landslide scars below Inferior Oolite outcrops identified on site visits associated with tilted trees.
- Springs draining into sinks down gullies associated with shallow landslide scarps and toes.
- History of landslide remediation, such as benching, counterfort drains, slumping behind house on Cold Slad Lane during landscaping works.
- Seepage from springs identified throughout slope.
- Debris flows.
- Gulls infilled with debris seen on site visits.
- Multiple debris flows identified to the west of Line of Section B, including debris channels.
- Debris flows vary in size from 15m to 124m, often forming ridges on the hillslope. The morphology of these debris flows does not appear to be degraded and hence may represent current conditions on the slope (i.e. not limited to association with glacial melt).
- Scree below limestone (IO) outcrop at top of Crickley Hill.
- Accumulation of quarrying debris at base of Inferior Oolite outcrop seen on site visits.
- Thick layer of colluvium sits above Lias Group.

Slope Hazard Zone 4

A.4.1.7 The key observations informing the hazard assessment in Slope Hazard Zone 4 and 4a (refer to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000003 in Appendix J are:

- Geomorphological evidence of backscarps within the mid-lower slope, with scarps between 5 and 30m width.
- Evidence of debris lobes flowing through gullies in the mid to lower slope on the east side of Slope Hazard Zone 4.
- No geomorphological evidence of deeper-seated failures within the upper slope, but evidence of a steep backscarp within the mid-slope and accumulation of relatively smooth toe material (possible ploughed land) indicating this deeper-seated landslide is ancient and probably slow moving.
- Within the lower slopes of Slope Hazard Zone 4a adjacent to the A417 Google street view appears to show straight, non-bent and non-tilted trees suggesting little active movement.

- Further upslope, up Dog Lane there is evidence from Google street view of large tilted trees.
- Evidence of springs emerging from around the level of the top of the backscarp. Gullies have formed, which disappear mid-slope (around the level of the inferred outcrop of the Marlstone Rock), which suggest the water is flowing back into the ground here.

Slope Hazard Zone 5

A.4.1.8 The key observations informing the hazard assessment in Slope Hazard Zone 5 (refer to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000002 in Appendix J) are:

- There is little geomorphological evidence for landslides within Slope Hazard Zone 5. This is likely due to the fact that the majority of the area has been reprofiled for use as a mountain bike facility. Due to the similar slope angle and slope direction to Slope Hazard Zone 6, it is considered that small to medium slips could have occurred.
- The slope averages about 11°, with steeper slightly slopes identified nearer the top and bottom of the slope. The lower slope, considered the area of highest risk, is at an angle of approximately 17°.
- Evidence of ridge and furrow in the mid to upper slopes, suggesting relative stability in this area since the Middle Ages.

Slope Hazard Zone 6

A.4.1.9 The key observations informing the hazard assessment in Slope Hazard Zone 6 (refer to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000001 in Appendix J) are:

- Geomorphological evidence of backscarps and landslide toes within the mid-lower slope. Backscarps are between 5m and 70m width.
- Benches of relatively steep slopes followed by relatively flat slopes in the upper part of the slope. It is possible that the larger plateaus, which are up to approximately 60m wide, could be representative of deeper-seated failures.
- Evidence of debris flow lobes within the lower slope.
- Ridge and furrow medieval plough system in part of the lower slope, suggesting relative stability in this area since the Middle Ages.

Slope Hazard Zone 7

A.4.1.10 The key observations informing the hazard assessment in Slope Hazard Zone 7 (refer to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000015 in Appendix J are:

- Presence of existing benched cuttings within the Inferior Oolite Formation.

A.4.2 Terrain analysis – Shab Hill

A.4.2.1 Terrain analysis provides geomorphological evidence for backscarps and landslide toes on the north and south facing slopes of Shab Hill valley. The most significant being that directly underlying the Scheme in the north-western extent of the valley.

Appendix B Geological and geomorphological mapping

B.1 Introduction

B.1.1.1 This appendix presents the results of geological and geomorphological mapping (historical and current) for the scheme.

B.1.1.2 Over the course of the project various geological and geomorphological studies have been carried out within the scheme area to better understand the stratigraphy, ground model and geological processes. On the basis of these studies the interpreted ground model and hence the interpretation of the surface outcrops has evolved, which now differs in places to the 1:50,000 BGS map. This appendix describes the differences and the evidence for proposed changes.

B.1.1.3 This report presents a number of proposed changes to the published geological mapping. The various sources of evidence that have been used to support any proposed updates and refinements to the BGS geological mapping have been described and an assessment of the relative level of confidence with respect to any changes to the BGS map is presented.

B.1.1.4 It is anticipated that as the project develops, more information is likely to become available, which can be used to further refine the interpretation of the ground model and geological map.

B.1.1.5 The reinterpreted geological map is presented on drawings HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 in Appendix J. Throughout the text reference is made to 'Geological Map Reference xx'. This refers to the numbered boundaries on HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 and can be cross referred to Table B-3.

Mapping area

B.1.1.6 The focus of the mapping was limited to the scheme extent defined by the red line in drawings HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 in Appendix J. However, where relevant other adjacent areas were mapped where it was considered this information would be useful to understand the disposition of the strata within the scheme extents.

B.1.1.7 The proposed reinterpretation of the geological map is presented on drawings HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 in Appendix J. The changes to the BGS published geology and the associated lines of evidence are described in proceeding sections and summarised in Table B-3.

Stratigraphy

B.1.1.8 The stratigraphical framework has been described in Section 3.4 of the report. More detail is provided within the PSSR and within the BGS's review of the stratigraphical interpretation from the Phase 2A ground investigation (provided in Appendix C of the GIR).

B.1.1.9 The framework follows the BGS Jurassic Stratigraphic Framework Reports (Barron et al 2012; Cox et al 1999). Full consideration of the biostratigraphy was not included.

B.2 Methodology

B.2.1 General

B.2.1.1 The information that has been used to develop the revised or reinterpreted geological map includes the following:

- Site walkover observations, including the mapping of geological exposures and geomorphological features. The findings and photographs from site walkovers are described in Appendix A.
- Terrain analysis and desk based geomorphological mapping using the results of a flown LiDAR survey.
- Aerial photography.
- The results of historical geomorphological mapping.
- Historical and more recent (i.e. Phase 1 and Phase 2A) intrusive ground investigations, including downhole geophysical logging.
- Surface geophysical investigations carried out as part of the Phase 2A ground investigation.

B.2.2 Site walkover

B.2.2.1 Arup carried out four site walkovers across the site throughout 2019. The observations made during these walkovers are presented in Appendix A and photograph locations are presented within HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000018; HE551505-ARP-EGT-X_XX_XXXX_X-DR-G- in Appendix J.

B.2.2.2 During the site walkover observed exposures were interrogated to understand the strata represented at outcrop. Bedding structure measurements (i.e. dip and dip direction) were also taken to inform the geological mapping. This has subsequently been used to inform geological mapping.

B.2.3 Terrain analysis

B.2.3.1 A detailed (0.25m horizontal resolution) Digital Terrain Model (DTM) model derived from an airborne LiDAR survey [1] was processed within ArcGIS to produce models of slope angle, slope aspect, curvature, catchment and hillshade (at various sun angles and azimuth).

B.2.3.2 These models were used to carry out detailed desk based geomorphological mapping of the landscape. This included identifying geomorphological features (e.g. breaks in slope, sloping ground, hummocky ground, depressions, level terrain) to inform an assessment of the disposition of strata boundaries.

B.2.3.3 The key findings of the geomorphological analysis using the DTM are presented below and presented within HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000001 to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000005 and HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000014 to HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000016 in Appendix J.

B.2.4 Aerial photography

B.2.4.1 Aerial photographs from 1946 to 1989 were available for examination from Historic England. In addition, publicly available Google Earth imagery was examined. Using the available photographs, it was possible to make observations of land use, soil colour and land quality. These variations were linked to possible changes in surface strata outcrops.

B.2.5 Historical geomorphological mapping

B.2.5.1 A number of walkovers and geomorphological surveys were undertaken during previous project phases, as summarised in Table B-1. The results of these surveys were reviewed to provide a complete assessment of all available information.

Table B-1 Previous walkovers and geomorphological surveys

Survey Date	Author	Report Title
Jun-Aug 1988 (a)	Edward J Wilson & Associates	Report on the Geomorphological Survey at Crickley Hill (A417), Gloucestershire, for the Highways Laboratory, Gloucestershire County Council.
Nov 1988 (b)	Edward J Wilson & Associates	Addendum Report to Geomorphological Survey at Crickley Hill (A417), Gloucestershire, for the Highways Laboratory, Gloucestershire County Council.
1991	Prof J N Hutchinson	A417 Crickley Hill Improvement: Geotechnical Investigations and Schemes for Road Widening on the Northern Valley Side.
Jan 2003 (a)	WSP	A417 Cowley to Brockworth Bypass Improvement: Preliminary Sources Study Report.
Jul 2003 (b)	WSP	A417 Cowley to Brockworth Bypass Improvement: Geomorphological Survey Report.
Apr 2017	Mott MacDonald Sweco Joint Venture	A417 Missing Link: Preliminary Sources Study Report.

B.2.6 Intrusive ground investigation

B.2.6.1 The scope of ground investigations is described within Section 4 of the GIR.

B.2.6.2 The results of intrusive ground investigations were used to support geological mapping. The verified disposition of strata boundaries recorded within exploratory holes were used to correlate the surface representation of the boundaries. Where possible intrusive ground investigation data was used to determine bedding dip and dip direction.

B.2.7 Geophysical investigations

B.2.7.1 The scope of geophysical investigations is described within Section 4 and Appendix D of the GIR.

B.2.7.2 Geophysical investigations comprised a mixture of electromagnetic conductivity (EM), electrical resistivity tomography (ERT) and seismic refraction (SR) surveys. These surveys were able to differentiate between materials with a stiffness and/or conductivity contrast, therefore the results were used to determine the strata surface outcrop. For example, FEF is a mudrock and weathers to a clay, whereas IO and GOG Limestone are solid limestone rock. Therefore, FEF is more conductive and less stiff than the resistive limestone strata (IO and GOG).

B.2.7.3 Geophysical surveys were also able to identify higher conductivity zones around faults, which indicates the presence of degraded rock quality and/or more weathered rock.

B.3 Summary of changes to the BGS map

Updates to published solid and superficial geology

B.3.1.1 On the basis of the information listed in Section B.2.1.1, the published geological map has been amended and is presented within HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 in Appendix J. The amendments are summarised below and more detail on the basis for changes and uncertainty is provided in Section B.4, B.4.1.34 and Table B-3. Throughout the text reference is made to 'Geology Mapping Reference'. This refers to the numbered boundaries on HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001 and -000002 in Appendix J, and can be cross referred to Table B-3.

- The boundary between the Inferior Oolite Formation and the underlying Lias Group has been refined, especially within the vicinity of the existing A417 towards the top of the escarpment slope (Geology Mapping Reference 5, 6, 8, 9 and 12).
- An outcrop of Fuller's Earth Formation has been presented to the north-east side of the Shab Hill Fault (Geology Mapping Reference 17).
- All geological boundaries within the Churn Valley-Shab Hill fault block have been refined. This includes the mapped extent of mass movement deposits on the north-western slope of Churn Valley (Geology Mapping Reference 18, 19, 20, 23 and 24).
- Within the Shab Hill Barn-Stockwell fault block all geological boundaries have been refined (Geology Mapping Reference 29, 30, 31, 32, 33, 34, 36, 44, 45, 46)
- The Great Oolite Group limestone does not appear to be as extensive as originally mapped by the BGS. A greater extent of the underlying 'Fuller's Earth Formation' is anticipated at ground surface from Ch 4+750 to Ch 5+500 (Geology Mapping Reference 40 and 41).
- An outcrop of Inferior Oolite has been presented within the base of Nettleton Bottom (Geology Mapping Reference 40 and 41).
- The mapped extent of mass movement deposits within Nettleton Bottom has been refined (Geology Mapping Reference 37).
- The thickness of Bridport Sand Formation is on average 20m thick but towards the south of the scheme thickness of greater than 37m can be found based on the borehole (DSRC315) that didn't penetrate the formation. This is thicker than the 0 to 10m thickness reported in the PSSR [2]. The formation also appears to be more laterally extensive from the escarpment than anticipated in the PSSR [2].
- Presence of Marlstone Rock is not consistently identified across the scheme. This may suggest it was not present as a continuous stratum, or it could be due to disturbance resulting from the escarpment forming processes or it may be deeper than anticipated.

B.3.1.2 Commentary on the above findings is presented on the selected geological cross sections presented in Appendix E.

Updates to the published structural geology

B.3.1.3 The surface trace of local and regional faults that extend through the scheme have been confirmed and/or refined on the basis of information listed in Section B.2.1.1. In addition, three new faults have been identified, including the following:

- Churn Valley Fault, which extends in a south-east to north-west orientation and downthrows to the south-west (Geology Mapping Reference 7, 10, 22 and 27).
- Cally Hill Fault, which extends in a south-west to north-east orientation and downthrows to the south-east (Geology Mapping Reference 35).
- Nettleton Bottom Fault, which extends in a north to south orientation and downthrows to the west (Geology Mapping Reference 47).

B.3.1.4 The key lines of evidence that have been used to map the positions of faults and commentary on the level of uncertainty is summarised below and more detail on the basis for changes and uncertainty is provided in Section B.6 and Table B-3.

B.4 Solid geology

Lias Group

B.4.1.1 Due to the superficial mass movement cover, the majority of the Lias Group outcrop is concealed within the limits of the scheme. It was possible to view one exposure of the Bridport Sand Formation of the Lias Group at Location 1 to 3 (7/11/2019 walkover) in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G- in Appendix J, (see Photograph 69 to 73 in Appendix A). At this location the unconformable boundary between the Leckhampton Member of the Inferior Oolite Group and the underlying Bridport Sand Formation of the Lias Group was observed at an elevation of approximately 220mOD. The boundary was traced along the outcrop for a distance of approximately 30m.

B.4.1.2 This verified position of the Lias Group/Inferior Oolite Group boundary has been used in combination with the results of intrusive ground investigation to model a proposed reinterpreted boundary (see Geology Mapping Reference 6).

B.4.1.3 An offset of this boundary was observed at Location 4 (7/11/2019 walkover) in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017 in Appendix J, (see Photograph 72 and 73 in Appendix A). This is interpreted to be due to the presence of a minor fault (Geology Mapping Reference 11), down throwing the strata approximately 5m to the north-east (Geology Mapping Reference 8).

B.4.1.4 Beyond the limits of the scheme and along the south facing escarpment of Crickley Hill (Geology Mapping Reference 5) the boundary between the Lias Group and the Inferior Oolite Group is based on strata contours of the top of the Lias Group. Strata contours were produced assuming a dip of 2° with a dip direction towards east-southeast (112°). This is based on a combination of published information (i.e. Hutchinson 1991) and assessment of dip slope angles in the area. Strata contours have been produced by using plotted exposures of the ‘Pea Grit’ member exposures and applying the known stratigraphical thickness.

B.4.1.5 On the north side of the Crickley Hill escarpment (Geology Mapping Reference 4) no amendments to the boundary shown on the published BGS map are proposed.

B.4.1.6 The Lias Group was not observed on the Barrow Wake side of the escarpment (Geology Mapping Reference 9 and 12). Here the boundary was informed by the level of the top of Lias in nearby exploratory holes and allowance of the local dip (assuming a dip of 2° with a dip direction towards east-southeast 112°).

B.4.1.7 On the south side of Barrow Wake (Geology Mapping Reference 12) no amendments to the boundary shown on the published BGS map are proposed.

Inferior Oolite Group

B.4.1.8 In general, there has been very little change to the outcrop of Inferior Oolite Group. The main changes affect the boundary between the overlying Fuller's Earth Formation, which is discussed in the proceeding section.

B.4.1.9 In addition to the observations of the Leckhampton Member, the Inferior Oolite Group was also observed at several locations around Crickley Hill and Barrow Wake, as described within Appendix A. The locations of these exposures were used to inform the mapping of the boundary between the IO and the underlying Lias Group.

Fuller's Earth Formation (FEF)

B.4.1.10 The FEF was not observed in exposures anywhere within the limits of the scheme. This stratum comprises grey, bedded silicate-mudstone, variably calcareous and grading to fossiliferous lime-mudstone with units of shell-rich limestone and well-bedded sandy limestone and calcareous sandstone.

B.4.1.11 The upper part of the FEF, composed of interbedded sandstone, mudstone, siltstone and limestone, has not been differentiated from the GOG Limestone. The boundary between FEF and the overlying Hampen Formation (Great Oolite Group Limestone) is gradational and interdigitates. Therefore, the 'top' of Fuller's Earth has been defined where the mudstones, siltstones and thin non-oolitic limestones are encountered in borehole logs. This is consistent with the published 1:50,000 and 1:10,000 scale geological map.

B.4.1.12 The BGS geological map indicates an absence of Fuller's Earth Formation to the north-east of the Shab Hill Fault. However, RC516 confirms the presence of 1.5m of this stratum overlying the Inferior Oolite Group. The mapped geological boundary (Geology Mapping Reference 17) corresponds to the level of the boundary in RC516.

B.4.1.13 In addition to this new outcrop of the Fuller's Earth Formation, the boundaries between this stratum and the underlying Inferior Oolite Group have been amended (Geology Mapping Reference 15, 26, 20).

B.4.1.14 The boundary between this stratum and the underlying Inferior Oolite Group within the Shab Hill-Churn Valley fault block (Geology Mapping Reference 15) has been informed by geophysical investigations (Line 20), which indicates a change from a resistive bedrock (interpreted to be IO) to a more conductive bedrock (interpreted to be FEF). This coincides with a break in slope from level terrain to a 10º slope, which is interpreted to represent the outcrop of the FEF, whereas the flat terrain represents the underlying IO. This also coincides with poorer quality soil, observed during a site walkover and an observation of darker soils (Google Earth Imagery from 04/2005).

B.4.1.15 The boundary between this stratum and the underlying IO within the Churn Valley-Shab Hill Barn fault block (Geology Mapping Reference 26) has been informed by a 2º strata dip to the south-east, which was proven by the relative difference in this boundary between RC520 and DSRCOH414 (assuming the top 5m of IO missing in this hole based on a typical 11m thickness of Salperton Limestone Formation). This also agrees with the assumed regional dip. This boundary coincides with a break in slope similar to that described in Section B.4.1.14 and an observation of darker soils (Google Earth Imagery from 04/2005).

B.4.1.16 Within Churn Valley the boundary between the FEF and the underlying IO (Geology Mapping Reference 20) has been moved approximately 250m up stream. This interpretation is based on a combination of geomorphological evidence, geophysical evidence (Line 23) and IO proven in exploratory holes at base of Churn Valley. Geomorphological evidence includes a break in slope and the presence of a flat-bottomed valley, which suggest the change from a less resistant bedrock (FEF) to a more resistant bedrock (IO). Geophysical investigations undertaken in Line 23 and Line 24 show the presence of a more resistive bedrock (beneath a thin superficial layer interpreted to be mass movement deposits). The more resistive bedrock was interpreted to represent IO, which was confirmed by intrusive investigation in DSRC11, TP605, DSRC310 and DSRC315.

B.4.1.17 Within the Shab Hill Barn-Stockwell fault block other similar amendments were made to the boundary between the FEF and the IO (Geology Mapping Reference 30, 31, 44). These amendments were based primarily on geomorphological evidence and aerial photography.

B.4.1.18 For Geology Mapping Reference 30, a combination of geomorphological evidence, including break in slope from level terrain to a 4 to 6º slope and a site observation of distinct change in soil colour (see Photograph 31 in Appendix A), is interpreted to represent the boundary between the IO and FEF. This approximately coincides with the level of the top of IO within the nearby intrusive exploratory hole (OH417).

B.4.1.19 Similarly, this boundary at Geology Mapping Reference 31 and 44 has been amended slightly to coincide with a break in slope and change in soil colour observed on aerial photos (Google Earth 04/2005).

B.4.1.20 South of the Stockwell Fault the FEF is interpreted to be far more widespread than the BGS map indicates. The is a significant amount of historical ground investigation within this part the scheme, which has indicated the absence of any oolitic limestone (i.e. GOG Limestone). Although not directly affecting the scheme, the GOG limestone is also interpreted to be absent to the west of Nettleton Bottom.

B.4.1.21 The geomorphology and intrusive investigations indicate the presence of the IO within the base of Nettleton Bottom (see Geology Mapping Reference 41). This is supported by the presence of a break in slope and a flat-bottomed valley bounded by slopes affected by mass movement (see Photograph 17 and 18 in Appendix A). These unstable slopes are interpreted to be within FEF and the break in slope marks the boundary between the FEF and underlying IO. The level of the IO/FEF boundary is supported by the verification of this boundary in nearby exploratory holes, including: DSRCOH400 (254mOD); 1989a_BH5A (249mOD); 1989a_BH4 (232mOD). Combined with the corresponding southernly dip, there is good evidence to support this interpreted boundary.

B.4.1.22 The boundary between the IO and FEF in the small faulted block immediately south of the Stockwell Fault (see Geology Mapping Reference 40) was interpreted on the basis of IO observed from the ground surface in exploratory holes 1990a_T123, 1990a_B317. The boundary also coincides with level of top of IO in DSRC329 (265mOD). There also appears to be some evidence of quarrying of this material.

B.4.1.23 Other indicators of FEF at outcrop included the presence of mass movement deposits. Landslides in the FEF are characterised by sharply defined backscarps at the edge of the Great Oolite Group limestone plateau. These were observed at in the Churn Valley during the Arup walkover (7 and 8 August 2019), as shown in Photograph 54 and 55 in Appendix A. The extent of mass movement deposits within the Churn Valley have been refined to account for these observations (see Geology Mapping Reference 19). These observations were supported by geophysical investigations (Line 23 and 24 and Zone 3 EM survey) and verified by intrusive investigations (in particular TP603, which identified relict shear surfaces).

B.4.1.24 Evidence for other forms of mass movement such as solifluction were identified in other areas through the terrain analysis. Hummocky ground to the south of the Shab Hill Barn fault (Geology Mapping Reference 28) and solifluction lobes around Stockwell Farm (Geology Mapping Reference 33) support the interpreted outcrop of this stratum.

Great Oolite Group – Limestone

B.4.1.25 As described within Paragraph B.4.1.11, the BGS map does not differentiate the upper part of the Fuller's Earth Formation, composed of interbedded sandstone, mudstone, siltstone and limestone, from the Great Oolite Group Limestone (limestones are taken to be equivalent to the Hampen and Taynton Limestone formations – Sumbler (1995) states that the locally named Througham Tilestones are equivalent to the Hampen Formation in the Gloucester District).

B.4.1.26 In accordance with the stratigraphic framework (Sumbler 1995), the GOG Limestones comprise grey to brown, thinly bedded, fine- to very fine-grained, ooidal grainstone to packstone with interbedded marl.

B.4.1.27 Therefore, interbedded limestone and mudstone can occur in both the top of the Fuller's Earth Formation and the overlying units (Taynton Limestone Formation and Hampen Formation) of the Great Oolite Group. For the purpose of ground modelling, oolitic limestones are likely to be more indicative of overlying Hampen Formation, whereas argillaceous, shelly limestones, likely to be more indicative of those within the Fuller's Earth Formation.

B.4.1.28 The GOG Limestone was observed at Location 46 (7-8/08/2019) and Location 11 to 14 (10/102019 walkover) in HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000017 in Appendix J, (see Photograph 51, Photograph 67 and 68 in Appendix A). At both exposures the rock comprised a pale pinky-yellow, well sorted medium to coarse grained oolitic limestone with closely to medium spaced beds.

B.4.1.29 At location 11 to 14 (Photograph 67 and 68 in Appendix A), whilst predominantly comprising oolitic limestone, a circa 300mm thick bed of marly fissile siltstone with limestone gravel was observed between the well sorted oolitic limestone. This outcrop is interpreted to be the GOG Limestone. The presence of GOG Limestone here is supported by geomorphological evidence, including terracettes on both the north and south facing side of the valley. This suggests the underlying strata comprises a bedded competent bedrock, such as the GOG Limestone.

B.4.1.30 Within the Shab Hill-Churn Valley fault block the boundary between the FEF and overlying GOG Limestone (Geology Mapping Reference 16 and 18) is slightly different to that presented by the BGS map. Geology Mapping Reference 16 has been interpreted on the basis of a break in slope from the a 10º slope to level terrain. The slope is interpreted to be controlled by the outcrop of the FEF, whereas the level terrain is interpreted to be controlled by the outcrop of the GOG Limestone. There are no nearby exploratory holes to confirm this, however as described within B.4.1.14, the outcrop of the FEF is supported by the observation of poorer quality soil observed during a site walkover and an observation of darker soils (Google Earth Imagery from 04/2005). At the break in slope the soils become lighter, as might be expected for limestone bedrock.

B.4.1.31 The location of the FEF-GOG Limestone strata boundary at the head of the Churn Valley (Geology Mapping Reference 18) is very different to that presented by the BGS map. This interpretation has been informed by a combination of geomorphological evidence, geophysical evidence, and intrusive evidence. Mass movement deposits were observed within the head of the valley (see Photograph 53 in Appendix A), which are interpreted to be within FEF and proven by TP603.

B.4.1.32 The strata boundary at Geology Mapping Reference 18 is supported by the data obtained through geophysical investigations. Electromagnetic mapping indicates the presence of a more resistive bedrock adjacent and evidence includes the presence of more resistive zone (GOG Limestone) underlain by a more conductive bedrock (FEF). This is also supported by the ERT and seismic results of Line 22, which shows a similar relationship in section. This is supported by intrusive investigation within TP636, which confirms the presence of GOG Limestone very close to the interpreted boundary.

B.4.1.33 Other supplementary evidence includes the presence of depressions, which are limited the GOG Limestone and IO outcrop. These depressions are interpreted to represent surface expressions of collapsed gull cavities or karst cavities.

B.4.1.34 The location of the FEF-GOG Limestone strata boundary within the Churn Valley-Shab Hill Barn fault block (Geology Mapping Reference 23 and 25) have similarly been defined by a break in slope between the sloping ground in FEF and the generally level terrain of the GOG Limestone. This is supported by the level of the top of FEF in intrusive exploratory holes within this fault block (DSRC412, OH411, RC520), which generally supports a 2º dip to the south-east.

B.4.1.35 Within the Shab Hill Barn-Stockwell fault block the interpreted boundaries between the FEF and the GOG Limestone (Geology Mapping Reference 32, 34, 36, 45, 46) are all slightly different to the BGS map. This is predominantly based on geomorphological evidence as described for other areas: Typically, the FEF outcrop forms a 5 to 10º slope, whereas the GOG Limestone forms level terrain.

B.4.1.36 These boundaries are further substantiated by the observation of darker surface soils coinciding with the FEF outcrop, with lighter soils coinciding with the GOG Limestone outcrop (Google Earth Imagery from 04/2005).

B.4.1.37 The outcrop of GOG Limestone is verified by a series of intrusive exploratory holes that encountered GOG Limestone from the surface (DSRC218, TP620, TP621, TP622, DSRC220, DSRC326, DSRC327, DSRC317). A number of the holes encountered more cohesive material at the surface (e.g. TP620 and TP622) which could be misconstrued to be FEF, however both trial pits (TP620 and TP622) refused on limestone, therefore they are interpreted to have encountered the interdigitating finer grained marly layers within the GOG Limestone.

B.4.1.38 GOG Limestone is interpreted to be absent south of the Stockwell Fault.

B.5 Structural geology

B.5.1.1 The location of faults has been confirmed or reinterpreted on the basis of a combination of geomorphological, geophysical and intrusive ground investigation evidence.

B.5.1.2 At the top of the escarpment intrusive data confirms the Shab Hill Fault downthrows approximately 5m to the north-east. The location of the fault is supported by geophysical survey data, including electromagnetic conductivity (EM), electrical resistivity tomography (ERT) and seismic refraction (SR) surveys. These surveys all indicate the presence of a more conductive and lower stiffness zone at the mapped position of the Shab Hill Barn Fault.

B.5.1.3 The trace of the Shab Hill Fault approximately follows the BGS mapped location but is amended slightly on the south facing slope of Shab Hill. Geomorphological evidence indicates the mass movement deposits are bounded on either side by a more competent bedrock. The Shab Hill Fault has therefore been amended according to this evidence.

B.5.1.4 A new fault referred to as the Churn Valley Fault has been mapped. This fault has been identified through geophysical investigations, including the EM, ERT and SR surveys (Line 23 and 24). The intrusive ground investigation data supports the postulated trace of the Churn Valley Fault. This fault is thought to have influence the formation of the prominent gully on the edge of the escarpment at Barrow Wake.

B.5.1.5 The Shab Hill Barn fault is mostly the same as the BGS mapped trace of the fault, except for some minor changes around the head of the Churn Valley to account for geomorphological evidence.

B.5.1.6 A potential new fault has been identified, referred to as the Cally Hill Fault. This fault extends north-east to south-west from Cally Hill towards Stockwell Farm. The downthrow is considered to be relatively minor to the south-east, however there is no conclusive intrusive data to verify this. The evidence supporting the hypothesised location of this new fault includes the presence of an incised gully at Cally Hill heading north-east into Churn Valley. A spring is present at the head of this gully, which is interpreted to be controlled by the presence of this structural lineation. To the south-west the trace of the fault follows a minor incision in the landscape, which abuts against the Stockwell Fault near Stockwell Farm.

B.5.1.7 The position of the Stockwell Fault has been confirmed by geophysical and intrusive ground investigation data. Within the scheme limits the fault position was shown to be 60m north of the BSG mapped location.

B.5.1.8 To the north of the fault intrusive exploratory holes (DSRC317 and TP627) encountered GOG Limestone from the ground surface, whereas to the south of the fault intrusive exploratory holes encountered FEF (DSRC329). This evidence indicates that the strata is downthrown to the north and the surface strata outcrop to the south of the Stockwell Fault is anticipated to be the FEF.

B.5.1.9 The trace of another new fault, referred to here as the Nettleton Bottom Fault, has been interpreted on the basis of the offset of the top of the IO within intrusive exploratory holes either side of Nettleton Bottom. On the west side of Nettleton Bottom 1989a_BH1 proves FEF to a level of 224mOD. On the east side of Nettleton Bottom the top of IO is proven in 1989a_BH2 (242mOD) and DSRCOH400 (254mOD). The absence of IO to the base of 1989a_BH1 (224moD) shows that the strata to the east of Nettleton Bottom has been downthrown relative to the west.

B.6 Superficial geology

B.6.1.1 Mass movement deposits have been mapped within the outcrop of FEF on the plateau area. Evidence includes the presence of solifluction lobes, arcuate backscarps and hummocky ground. There is also convincing geomorphological evidence for backscarps and landslide toes on the north and south facing slopes of Shab Hill valley. The most significant being that directly underlying the Scheme in the north-western extent of the valley.

B.6.1.2 Mass movement deposits on the escarpment slopes have been mapped using the results of field and desk based geomorphological mapping, combined with the results of extensive intrusive ground investigation and geophysical investigations. All lines of evidence have been used to not only map the extent of mass movement deposits, but also develop a conceptual understanding of movement mechanisms.

B.7 Summary of geological mapping

B.7.1.1 Table B-3 presents a summary of evidence used to derive geological boundaries within the limits of the scheme. Where boundaries have been 'amended', this is in reference to the BGS 1:50,000 scale mapping. If the answer is 'no' then the boundary remains as per the BGS map and there is no evidence for the contrary.

B.7.1.2 Geological mapping is inherently based on using multiple lines of evidence to interpret the location of a boundary. The level of certainty has been based on a qualitative framework, whereby Red = low confidence; Amber = moderate confidence; yellow = moderately high confidence; Green = high confidence.

Table B-2 Framework for mapping confidence levels

Confidence	Relative confidence level	Example of evidence used
Red	Low	Based on geomorphological evidence only
Amber	Moderate	Based on geomorphological evidence and one or more other line of non-verifiable evidence (i.e. aerial photography or geophysical investigations)
Yellow	Moderately high	Based on geomorphological evidence and one or more other line of verifiable evidence (i.e. intrusive ground investigation)
Green	High	Based on direct observation of geological boundary

Table B-3 Summary of mapping evidence

Geology Mapping Reference	Feature type	Feature description	Feature amended?	Evidence for boundary / feature	Level of confidence
1	Superficial boundary	Boundary between superficial Cheltenham Sand and Gravel and the Charmouth Mudstone Formation	No	BGS	N/A
2	Superficial boundary	Boundary between superficial Cheltenham Sand and Gravel and the Charmouth Mudstone Formation	No	BGS	N/A
3	Superficial boundary	Boundary between mass movement deposits and the Charmouth Mudstone Formation	No	BGS	N/A
4	Solid boundary	Boundary between the IO and the Lias Group / mass movement deposits	No	BGS	N/A
5	Solid boundary	Boundary between the IO and the Lias Group / mass movement deposits	Yes - slight amendment to BGS boundary along south facing escarpment of Crickley Hill	Boundary based on strata contours of the top of the Lias Group. Produced by using mapping locations of Pea Grit exposures and applying the known stratigraphical thickness.	Amber
6	Solid boundary	Boundary between the IO and the Lias Group / mass movement deposits	Yes - slight amendment to BGS boundary along south facing escarpment of Crickley Hill	Boundary based on observation of the boundary between the Inferior Oolite Group and the underlying Lias Group.	Green
7	Fault	Extension of the newly identified Churn Valley Fault	New	Geomorphological evidence. No direct observation of fault.	Red
8	Solid boundary	Boundary between the IO and the Lias Group / mass movement deposits	Yes	Boundary based on observation of the Leckhampton Member of the Inferior Oolite Group (lowest member). Level of boundary aligns with that proven in nearby boreholes.	Green

Geology Mapping Reference	Feature type	Feature description	Feature amended?	Evidence for boundary / feature	Level of confidence
9	Solid boundary	Boundary between the IO and the Lias Group / mass movement deposits.	Yes	Boundary based on level proven in nearby boreholes.	Yellow
10	Fault	Extension of the newly identified Churn Valley Fault.	New	Geomorphological evidence (i.e. gully) and geophysical evidence from Line 20. Line 20 indicates the presence of a rapid change in stratum from a conductive and less stiff material to a resistive and relatively stiffer material at the location of the fault. No direct observation of fault.	Yellow
11	Fault	Minor fault located on the upper slopes of Crickley Hill.	New	Direct observation of offset of Leckhampton Member of the Inferior Oolite Group.	Green
12	Solid boundary	Boundary between the IO and the Lias Group / mass movement deposits.	Yes	Geomorphological evidence (i.e. break in slope) coinciding with the expected level of outcrop based on a 2-degree bedding dip to the south-east (dip proven for fault block based on change in level of top of Inferior Oolite Group between DSRCOH414 and RC520). Other evidence includes presence of a rapid flowing spring (in winter) at the boundary and the absence of quarries.	Yellow
13	Solid boundary	Boundary between the IO and the Lias Group / mass movement deposits.	No	BGS	N/A
14	Fault	Shab Hill Fault	No	BGS. Geophysical investigations indicate the presence of a fault at the location of the mapped Shab Hill Fault.	N/A
15	Solid boundary	Boundary between IO and overlying FEF.	Yes, boundary moved approx. 80m to the north-west.	Geophysical investigations indicate a change from a resistive bedrock (IO) to a more conductive bedrock (FEF). This coincides with a break in slope. The slope is interpreted to represent the outcrop of the FEF, whereas the flat terrain represents the underlying IO. This also coincides with poorer quality soil, observed	Amber

Geology Mapping Reference	Feature type	Feature description	Feature amended?	Evidence for boundary / feature	Level of confidence
				during a site walkover and an observation of darker soils (Google Earth Imagery from 04/2005).	
16	Solid boundary	Boundary between FEF and GOG limestone.	Yes, boundary moved approx. 50m to the north-west.	The change in terrain from level terrain to sloping terrain is interpreted to mark the boundary between the GOG and the underlying FEF. The slope is interpreted to represent the outcrop of the FEF, whereas the flat terrain represents the overlying GOG. The FEF outcrop also coincides with poorer quality soil, observed during a site walkover and an observation of darker soils (Google Earth Imagery from 04/2005).	Amber
17	Solid boundary	Boundary between IO and overlying FEF.	New boundary	Thin cover (1.5m) of FEF proven with RC516.	Yellow
18	Solid boundary	Boundary between FEF and GOG limestone.	Yes, boundary moved approx. 100m to the north-west.	Combination of geomorphological evidence, observation of mass movement deposits within FEF, geophysical evidence from Line 22 and the Zone 3 EM survey, intrusive verification (TP636 and TP603).	Yellow
19	Superficial boundary	Boundary of mass movement deposits.	Yes, extent of mass movement deposits has been refined	Combination of geomorphological evidence, including hummocky ground and backscarps. Observation of mass movement deposits within FEF during site walkover, geophysical evidence from Line 23 and the Zone 3 EM survey and intrusive verification (TP603).	Yellow
20	Solid boundary	Boundary between IO and overlying FEF.	Yes, boundary moved approx. 250m up valley (north-west)	Combination of geomorphological evidence, geophysical evidence (Line 23) and IO proven in exploratory holes at base of Churn Valley.	Yellow
21	Fault	Shab Hill Fault	Yes, fault moved slightly further south within the base of Churn Valley	Geomorphological evidence including the presence of a steep slope to the east, interpreted to be a slope in limestone (IO) rather than FEF. Abrupt change in slope morphology	Red

Geology Mapping Reference	Feature type	Feature description	Feature amended?	Evidence for boundary / feature	Level of confidence
				suggest this could be controlled by the presence of the Shab Hill Fault.	
22	Fault	Churn Valley Fault (eastern extent - in Churn Valley).	New features	Geomorphological evidence, including presence of deformed valley slope in FEF and flat-bottomed valley (interpreted to be on IO). Geophysical evidence (Line 23 and 24) includes abrupt change in electromagnetic conductivity and stiffness of the bedrock at the location of the Churn Valley Fault. Offset in bedrock proven in exploratory holes either side of the fault interpreted to be due to faulting.	Yellow
23	Solid boundary	Boundary between FEF and GOG limestone.	Yes, amended slightly	Combination of geomorphological evidence, intrusive exploratory holes, geophysical evidence (Line 23 and 24 and EM mapping) indicates more extensive FEF than the BGS presents.	Yellow
24	Solid boundary	Boundary between FEF and overlying GOG limestone.	New outcrop of Fuller's Earth Formation at the base of the top of Churn Valley	Based on level of FEF in nearby exploratory holes	Yellow
25	Solid boundary	Boundary between FEF and overlying GOG limestone.	Yes, outcrop amended significantly	Geomorphological evidence (i.e. break in slope) coinciding with the expected level of outcrop based on a 2-degree bedding dip to the south-east (dip proven for fault block based on change in level of top of Inferior Oolite Group between DSRCOH414 and RC520). Aerial photo evidence for FEF in field.	Amber
26	Solid boundary	Boundary between IO and overlying FEF.	Yes, outcrop amended significantly	Top of IO (excluding approx. top 5m) proven within DSRCOH414. Geophysics Line 20 indicates bedrock of higher resistivity on the south side of the Churn Valley Fault.	Amber
27	Fault	Churn Valley Fault (Churn Valley head)	New features	Geomorphological evidence, including presence of deformed valley slope in FEF and flat-bottomed valley (interpreted to be on IO).	Yellow

Geology Mapping Reference	Feature type	Feature description	Feature amended?	Evidence for boundary / feature	Level of confidence
				Geophysical evidence (Line 23 and 24) includes abrupt change in electromagnetic characteristics and stiffness of the bedrock at the location of the Churn Valley Fault. Offset in bedrock proven in exploratory holes either side of the fault interpreted to be due to faulting.	
28	Fault	Shab Hill Barn Fault	Yes, trace of fault shifted slightly to south-west	Geomorphological evidence, including break of slope and gully to the south-east. Abrupt change in slope morphology suggests this could be controlled by the presence of the Shab Hill Barn fault.	Red
29	Superficial boundary	Mass movement deposits	New features	Geomorphology and aerial photography evidence indicate an area of hummocky ground within an outcrop of FEF, which suggests that the slope has been subjected to solifluction.	Amber
30	Solid boundary	Boundary between IO and overlying FEF.	Yes, outcrop amended slightly	Geomorphological evidence, including break in slope, interpreted to be between slope in FEF and level terrain in IO. Site observation evidence of distinct change in soil colour at boundary between FEF and IO. Intrusive exploratory holes (OH417) prove top of IO.	Yellow
31	Solid boundary	Boundary between IO and overlying FEF.	Yes, outcrop amended slightly	Geomorphological evidence, including break in slope, interpreted to be between slope in FEF and dip slope (shallow to south-east) in IO. Aerial photo evidence (Google Earth 04/2005) indicates changes in soil colour.	Amber
32	Solid boundary	Boundary between FEF and overlying GOG limestone.	Yes, outcrop amended slightly, approx. 100m to west and north	Geomorphological evidence, including change in slope aspect and break in slope between the level terrain (interpreted to be GOG limestone) and sloping ground (interpreted to be FEF).	Yellow
33	Superficial boundary	Mass movement deposits	Yes, extent of mass movement deposits refined	Geomorphological and aerial photography evidence for the presence of solifluction lobes.	Amber

Geology Mapping Reference	Feature type	Feature description	Feature amended?	Evidence for boundary / feature	Level of confidence
34	Solid boundary	Boundary between FEF and overlying GOG limestone.	Yes, outcrop amended slightly	Geomorphological evidence, including flat terrain (interpreted to be GOG limestone) and break in slope (interpreted to be FEF). Aerial photograph evidence (Google Earth 12/1995) shows darker soil at outcrop of FEF.	Yellow
35	Fault	Cally Hill Fault	New	Topographic features, including a north-east to south-west trending gully extending steeply into Churn Valley. This feature extends across the outcrop of FEF and GOG limestone, albeit more subtle. Observed offset between FEF at the top of Nettleton Bottom Valley (at Stockwell Farm). Site visit observation of GOG limestone in artificial cutting at the top of Nettleton Bottom.	Amber
36	Solid boundary	Boundary between FEF and overlying GOG limestone.	New	Geomorphological evidence of strata changes here. Level of outcrop coincides with expected dip (few degrees to the south - based on dip slope) and the top of FEF encountered in exploratory holes to the north-east (DSRC220, DSRC326, DSRC327 and DSRC317)	Red
37	Superficial boundary	Mass movement deposits	Yes, extent of mass movement deposits refined	Geomorphological and site observation evidence for hummocky ground and shallow slips.	Amber
38	Fault	Stockwell Fault	Yes, moved fault to north approx. 60m	Based on geophysical evidence in Line 25, 26 and the EM survey. Intrusive exploratory hole TP627 proves GOG limestone on the north side of the fault, whereas DSRC329 proves FEF at the surface, underlain by IO at shallow depth.	Green
39	Fault	Minor fault	New	Top of IO offset between DSRC329 (265mOD) and DSRCOH400 (254mOD) over a distance of only 100m has been interpreted to be due to the presence of a minor fault. This also coincides with a gully, which could be structurally controlled.	Amber

Geology Mapping Reference	Feature type	Feature description	Feature amended?	Evidence for boundary / feature	Level of confidence
40	Solid boundary	Boundary between IO and overlying FEF.	New	IO observed in exploratory holes 1990a_T123, 1990a_B317. Steep valley side with terracettes indicating limestone bedrock. Boundary coincides with level of top of IO in DSRC329 (265mOD)	Yellow
41	Solid boundary	Boundary between IO and overlying FEF.	Yes, IO boundary approx. 300m north	Geomorphological evidence in the form of a flat-bottomed valley. Level of IO corresponds with the top level of IO in DSRCOH400 (254mOD), 1989a_BH5A (249mOD), 1989a_BH4 (232mOD) and the corresponding southernly dip.	Yellow
42	Solid boundary	Boundary between the IO and overlying FEF	No	BGS	N/A
43	Solid boundary	Boundary between the IO and overlying FEF	No	BGS	N/A
44	Solid boundary	Boundary between IO and overlying FEF.	No	BGS. Further evidence includes break in slope (flat terrain = IO; sloping ground = FEF) and aerial photo evidence (12/1999).	N/A
45	Solid boundary	Boundary between FEF and overlying GOG limestone.	Yes, amended slightly	Geomorphological evidence, including break in slope. Verified by FEF boundary at 276mOD in DSRC220mOD.	N/A
46	Solid boundary	Boundary between FEF and overlying GOG limestone.	New	Geomorphological evidence of strata changes here. Level of outcrop coincides with expected dip (few degrees to the south - based on dip slope) and the top of FEF encountered in exploratory holes to the north-east (DSRC220, DSRC326, DSRC327 and DSRC317).	Red
47	Fault	Nettleton Bottom Fault	New	Offset between top of IO to the east (e.g. 1989a_BH1, encountered FEF to a level of 224mOD, but didn't prove the base) and the west (e.g. 1989a_BH2, which encountered the top of IO at 242mOD).	Yellow

B.8 References

[1] L. S. L. Malcom Hughes, “A417 Missing Link Airborne LiDAR and topographical survey. Report reference 52310,” 2019.

[2] Mott Macdonald Sweco Joint Venture, “A417 Missing Link. Preliminary sources study report. PCF Stage 2. HA GDMS 30509,” May 2018.

Appendix C BGS stratigraphical logging note

A417 Missing Link at Air Balloon: Review of stratigraphical interpretation from Phase 2A ground investigation

National Geoscience Programme
Commissioned Research Report CR/20/059
September 2020

BRITISH GEOLOGICAL SURVEY

NATIONAL GEOSCIENCE

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A417 Missing Link at Air Balloon: Review of stratigraphical interpretation from Phase 2A ground investigation

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Executive Summary

This report provides a summary of the stratigraphical interpretation of five boreholes drilled as part of the Highways England contract ‘Collaborative Delivery Framework Lot 1 – A417 Missing Link at Air Balloon Cross’. The British Geological Survey (BGS) provided sub-consultancy services to Highways England’s consultant (Ove Arup & Partners). The BGS was appointed to undertake stratigraphical and lithological check logging of five cores drilled in the Birdlip area to provide a baseline for defining group and formation boundaries in accordance with the published lithostratigraphical scheme and stratigraphical framework for the Lower and Middle Jurassic strata. This would be used by the Ground Investigation contractor, Geotechnical Engineering Ltd (GEL) to develop their engineering geological logs and ultimately assist Highways England’s consultants to inform and develop the project ground model.

The continuous rotary core samples provided to BGS for check-logging represent Jurassic strata including Lias Group, Inferior Oolite Group and Great Oolite Group sedimentary rocks. The formations encountered include (in ascending order) the Dyrham Formation (DYS), Marlstone Rock Formation (MRB), Whitby Mudstone Formation (WHM), Bridport Sand Formation (BDS), Birdlip Limestone Formation (BLPL), Aston Limestone Formation (ASLS), Salperton Limestone Formation (SALS), and Fuller’s Earth Formation (FE). The Birdlip Limestone Formation has been logged to Member level, distinguishing Leckhampton Member, Crickley Member, Cleeve Cloud Member, Scottsquar Member and Harford Member. The Aston Limestone Formation is thin in the project area. The Upper Trigonia Grit and Clypeus Grit Members of the Salperton Limestone Formation are distinguishable by their fossil content and have been separated where possible. Computer code abbreviations used in this report conform with BGS Lexicon of Named Rock Units (https://www.bgs.ac.uk/technologies/the-bgs-lexicon-of-named-rock-units/)

The Upper Trigonia Grit and base of Leckhampton Limestone display distinct gamma-ray peaks that will aid stratigraphical correlation between boreholes. The Marlstone Rock, where encountered, provides a marker bed that is useful for interpreting landslide architecture and regional structure. Logging confirmed the presence of superficial and mass movement deposits including solifluction and gelifluction deposits (HEAD), landslide deposits (SLIP) and colluvium (COLV).

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1 Introduction

This report provides a summary of the stratigraphic interpretation of five boreholes drilled as part of the Highways England contract 'Collaborative Delivery Framework Lot 1 – A417 Missing Link at Air Balloon Cross'. The BGS provided sub-consultancy services to Highways England's consultant (Ove Arup & Partners).

Schedule 2 of The Contract states that:
"S1.10.5 of the ground investigation (GI) specification (HE551505-MMSJV-HGT-000-SP-CE-00001) states that lithological geological logs are to be prepared by the BGS. An interpretation of the stratigraphy is also required."

"The scope of works comprises the review of stratigraphical interpretation from the Phase 1 and ongoing Phase 2A ground investigations, including check logging, and preparation of lithological and stratigraphical geological logs for selected boreholes (allowance for 5 no. boreholes up to 100m depth)."

This would provide a baseline for defining group and formation boundaries in accordance with the published lithostratigraphical scheme and stratigraphical framework for the Lower and Middle Jurassic strata. This would be used by the Ground Investigation contractor, GEL, to develop their engineering geological logs and ultimately assist Highways England's consultant to develop the ground model.

The involvement of the BGS in core logging and geological QA originated from earlier discussions with Mott MacDonald in June 2017 and was followed up by ARUP. Specifically, the *Proposed Investigation* section of the A417 Missing Link Preliminary Sources Study Report: PEI Report, Appendix 9.2 (Highways England, Sept 2019) states the following:

> *"**Exploratory hole logging**:*
>
> *12.7.26*
>
> *Accurate logging of exploratory holes is extremely important; once the fieldwork is complete it forms the main representation of the intrusive fieldwork. It is required that all holes will be logged as per industry standard Geotechnical logging – BS EN ISO 14688-1, BS EN ISO 14688-2 and BS EN ISO 14689-1. It is also required that these descriptions be supplemented with lithological details and weathering classification (e.g. (Hobbs, et al., 2012)) to accurately identify the formations within the Great Oolite, Inferior Oolite and Lias Group.*
>
> *12.7.27*
>
> *To achieve the requirement for lithological logging, it is proposed that the British Geological Survey (BGS) is engaged to assist with field identification during the initial stages of the deep borehole drilling and then commissioned to undertake selected lithological logs of certain boreholes. It is also required that a BGS specialist in the Great Oolite, Inferior Oolite and Lias Group attend site on a minimum of 5 separate occasions to undertake lithological logs of select holes which will be used as high-quality correlations for the scheme."*

A BGS geologist's attendance on site during the initial stages of drilling (Phase 1) was not possible due to delays around contract Terms and Conditions and so BGS staff input was reduced to inspection and stratigraphical and lithological check logging/QA of 5 cores after the second stage of drilling (Phase 2A). A field-based workshop was planned for early 2020 but cancelled due to COVID-19 virus travel restrictions imposed on BGS-NERC staff.

The core material from GEL boreholes #109, 224, 308, 400, 418 were transported by lorry from GEL's store in Gloucester to BGS Keyworth (Nottingham) core store for examination. The boreholes were drilled out as part of the Phase 2A ground investigation activities. The cores arrived in Keyworth on 5 August 2020. Transport of core and socially distanced logging at BGS core store was required to meet BGS' COVID-19 virus secure working policy. GEL's factual borehole logs and various geophysical logs (optical image, caliper, gamma, fluid temperature/EC, Density) were provided as reference material (draft engineering logs, geophysical logs, core photos) and these data were reviewed in conjunction with the core inspection.

The contract specified the following tasks:

1. Review of stratigraphical interpretation from selected Phase 2A ground investigation (including check logging) and prepare lithological and stratigraphical geological logs for selected boreholes (allowance for 5 cores with a total length of 408m)
2. Prepare a technical note describing objectives; framework for Stratigraphical logging; and findings
3. Prepare a register of observations and suggested changes to logging for GEL to action.

This report delivers on this part of the GI specification and the output of Tasks 1-3 described above.

2 Objectives

The stratigraphical framework will be used by the GI contractor (GEL) to update their existing engineering geological logs. The objective of BGS' input was to provide accurate stratigraphical boundaries to inform the project ground model and allow reliable correlation between boreholes. This work enables identification of key geological features, such as changes in thickness of units/aquifers, structures (folds, faults, shears), to understand landslide mechanisms and depth/geometry of slip planes and landslide mass volumes, and to ascertain the geotechnical effects of cambering/valley bulging processes and gull formation (potential for weak zones and voids). All these factors will affect the design and construction programme, and project cost at various points along the project life and should be understood to appropriate levels and incorporated into the project ground model. Crickley Hill is set within the Cotswolds Area of Outstanding Natural Beauty (AONB) and includes four designated Sites of Special Scientific Interest (SSSI), including Limestone Grassland. The area is one of classic British geology and the core retrieved from these sites is of scientific interest for Jurassic research.

3 Framework for stratigraphic logging

The framework adopted for the logging follows BGS Jurassic Stratigraphic Framework Reports (Barron et al 2012; Cox et al 1999), and builds on several published peer-reviewed research papers, geological memoirs, and special publications (Cox and Sumbler, 2002; Sumbler et al, 2000; Barron et al 1997; Mudge 1978a&b). The system is in agreement with the system presented in the A417 Missing Link Preliminary Sources Study Report: PEI Report, Section 3.1 – Geology (Highways England, Sept 2019) and an earlier PSSR (2003) report. Diagnostic fossils (e.g. Trigonia bivalves) were noted, but a full biostratigraphic study was outside the scope of work. Important non-stratigraphic features (faults, shears, karst features, gulls, unconformities) were noted but detailed description of such features was outside of scope.

Table 1 provides a summary of the main stratigraphic divisions currently adopted for the north Cotswolds area. Figure 1 provides an overview of the main lithological units and structure in relation to the A417 Road Improvement Scheme, broadly the area between Birdlip and Leckhampton Hill in the figure.

Table 1 – Bedrock lithostratigraphic framework suggested for ‘A417 Missing Link’ project. Adapted from Barron et al. 1997) and based on the Generalised Vertical Section of the north Cotswolds (BGS 1:50 000 map Sheet 217) and the Cirencester Memoir (Sumbler et al. 2000).

Group name	Typical Formation thickness in Birdlip area	Member name	Informal Subdivisions
Great Oolite Group (GOG)	Fuller’s Earth (FE) 12-24m		
Inferior Oolite Group (INO)	Salperton Limestone Formation (SALS) 10m	Clypeus Grit Member (CG)	
		Upper Trigonia Grit Member (UTG)	
	Unconformity		
	Aston Limestone Formation (ASLS) 0-5m	Gryphite Grit member (GG) Lower Trigonia Grit Member (LTG)	
	Unconformity		
	Birdlip Limestone Formation (BLPL) 35-50m	Harford Member (HFD)	
		Scottsquar Member (SQAR)	
		Cleeve Cloud Member (CLCL)	‘Devil’s Chimney Oolite’ ‘Fiddler’s Elbow Limestone’
		Crickley Member (CRKY)	‘Pea Grit’ ‘Lower Limestone’
		Leckhampton Member (LECK)	
Lias Group (LI) [Lower Jurassic]	Unconformity		
	Bridport Sand Formation (BDS) 20-25m		
	Whitby Mudstone Formation (WHM) c.60m		
	Marlstone Rock Formation (MRB) 1-3m		
	Dyrham Formation (DYS) 30m		Note sandstone bed in upper part
	Charmouth Mudstone Formation (CHAM) 250m		
	Blue Lias Formation (BLI) 80m		

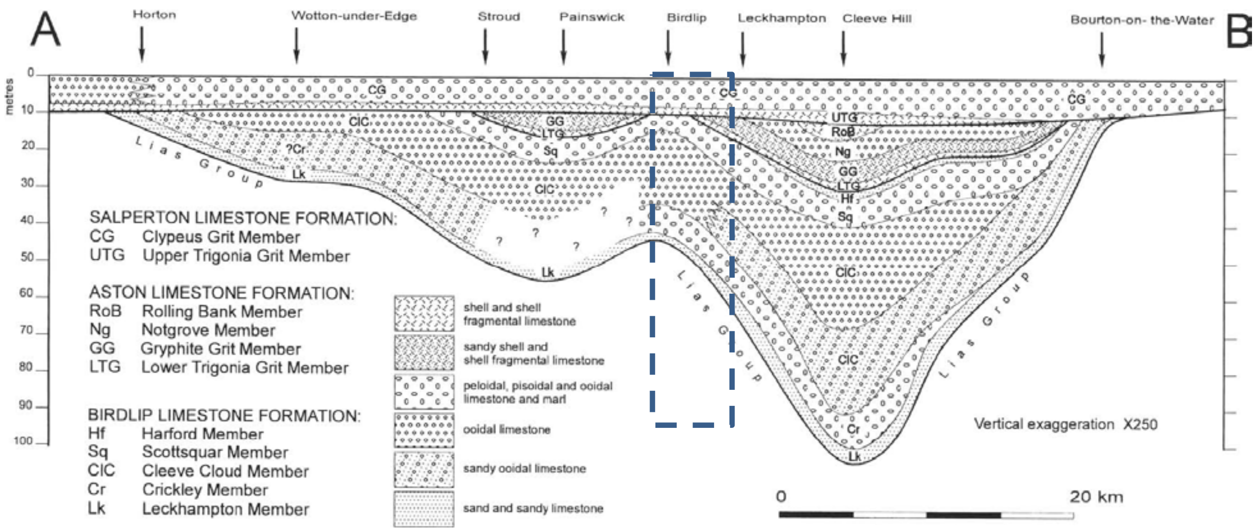


Figure 1 Sketch cross section (Barron et al 1997, Fig 5) showing generalised lithologies, broad structure, and mutual relationships in relation to Birdlip area. Note the extreme vertical exaggeration. Dashed area represents general stratigraphy in A417 study area. Section orientated roughly southwest (A) to northeast between Horton and Cleeve Hill, and west to east between Cleeve Hill and Bourton-on-the-Water (B). Reproduction is with the consent of the Geologists' Association.

4 Findings

4.1 EXPORATORY HOLES

The exploratory holes selected for logging are shown in Figure 2. The holes were selected for logging based on geographical spread, Formation spread, and longest holes to get a full sequence through the project area. Hole DSRC244 (note the prefix DSRC indicated the drilling method: Dynamic Sampler followed by Rotary Core)

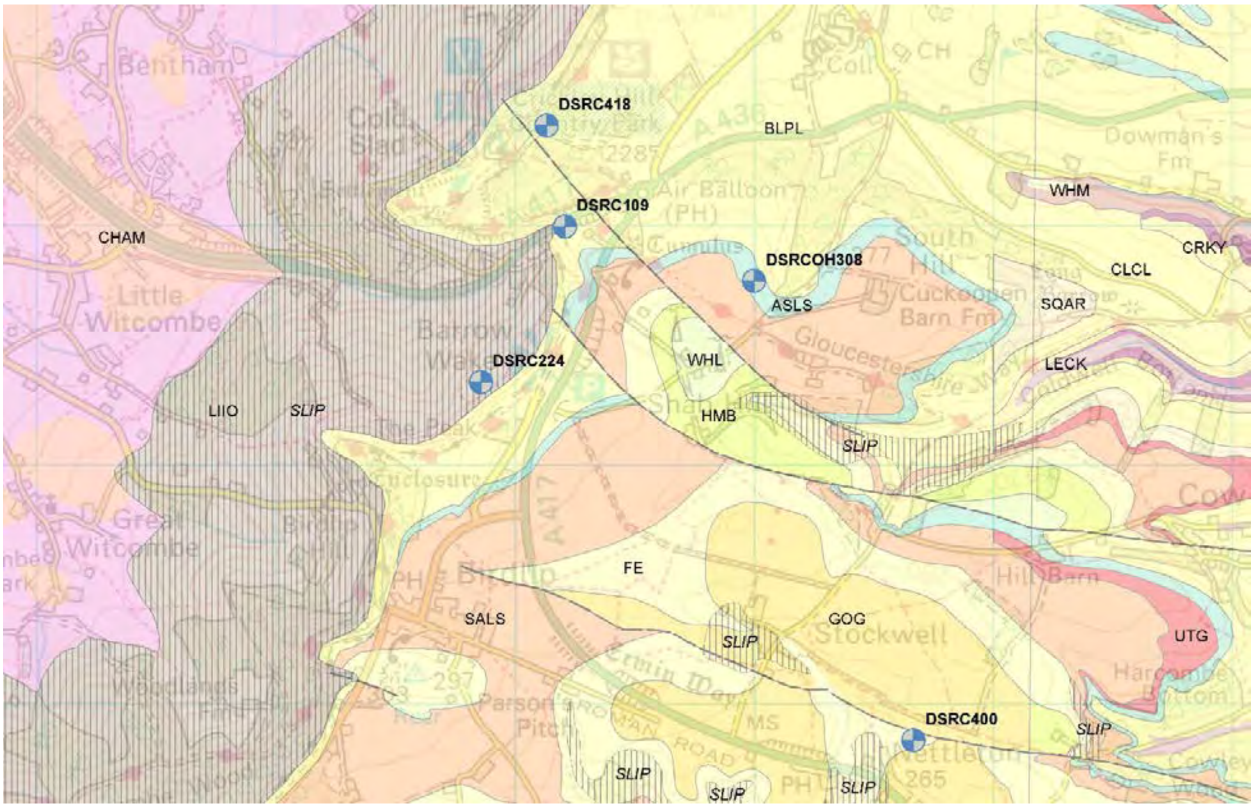


Figure 2 Map showing location of BGS-logged Phase IIA boreholes and 1:50 000 scale surface geology (BGS © UKRI). Contains Ordnance Survey data © Crown copyright and database right 2020.

NB: HMB is the Hampen Formation and WHL the White Limestone Formation – locally distinguished units of the Great Oolite Group above the Fuller's Earth. LIIO indicates the outcrop of the undifferentiated Lias Group and Inferior Oolite Group beneath the landslides.

4.2 STRATIGRAPHICAL SUMMARY – FORMATION LEVEL

This section contains tables summarising the Formation boundaries. See Appendix for Member level details. The intention is that these formation depth boundaries will be integrated into the final project Borehole Logs (GEL) to support stratigraphical and lithological ground model development and for developing slope stability models.

Table 2. Borehole stratigraphical summary DSRC #400.

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Formation Code	Comment
E:394666, N: 213848, Ground Level = 267.95m aOD				
13.31	13.31	254.64	FE	Brown silty clay
10.86	24.17	243.78	SALS	Limestone
0.83	25.00	242.95	ASLS	Limestone
52.15	77.15	190.8	BLPL	Limestone, well bedded and karstified
13.80	>90.95	Base not reached	BDS	Very-weak to weak laminated fine sands and silts

Table 3. Borehole stratigraphical summary DSRC #418.

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Formation Code	Comment
E: 393132, N: 216419, Ground Level = 272.25m aOD				
1.20	1.20	271.05	HEAD	Brown clay
57.67	58.87	213.38	BLPL	Moderately-strong to very-strong karstified limestone. Possibly ASLS present near top.
2.63	>61.50	Base not reached	BDS	Laminated fine sands and silts

Table 4. Borehole stratigraphical summary DSRC #109.

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Formation Code	Comment
E: 393208, N: 215995, Ground Level = 233.00m aOD				
1.20	1.20	232.8	HEAD	Brown clay
19.75	20.95	212.05	BLPL	Limestone
29.05	50.00	183.00	BDS	Very-weak laminated fine sands and silts, with c.2m of dark silty mudstone at top. Some 'tentative' shear zones identified possibly related to cambering.
>55.00	>105.00	Base not reached	WHM	Silty mudstone

Table 5. Borehole stratigraphical summary DSRCOH #308

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Formation Code	Comment
Ground Level = 271.35m aOD				
4.80	3.55	267.80	SALS	Limestone. CG and UTG Members present. Trigonia shells present.
1.10	4.45	266.90	ASLS	Limestone
54.66	59.11	212.24	BLPL	Leckhampton Member at base.
>11.29	>70.40	Base BDS not reached	BDS	Ex.-weak laminated fine sands and silts, with dark silty mudstone at top

Table 6. Borehole stratigraphical summary DSRC #224

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Formation Code	Comment
E: 392857.0, N: 215346.0 Ground Level = 226.85. Southern Cotswolds Escarpment.				
0.60	0.60	226.25	MGR	
2.90	3.50	223.35	COLV & HEAD	Talus or Rubble (Limestone gravel/cobbles).
15.50	19.00	207.85	SLIP-BDS	Laminated silt and sand, slipped, deep-seated rotational landslide.
50.00	69.00	157.85	SLIP-WHM and WHM	Laminated mudstone, Possible slip surfaces/shears down to c.40m depth.
1.05	70.05	156.8	MRB	Limestone, pebbles of brown sideritic siltstone at base. Key marker horizon.
>10.45	>80.50	Base not reached	DYS	Mudstone and siltstone. Non-calcareous sandstone bed at 75.3 – 76.15m.

4.3 CONCLUSIONS

- The continuous rotary core samples provided >90% core recovery enabling stratigraphical logging of the full sequence. Geophysical logs (Gamma, Image) were reviewed and found to be very useful for correlation of Formations (and Members) and aided stratigraphical boundary picks.
- The combination of cores represent Lias Group, Inferior Oolite Group and Great Oolite Group sedimentary rocks. The formations encountered (oldest to youngest) include the Dyrham Formation (DYS), Marlstone Rock Formation (MRB), Whitby Mudstone Formation (WHM), Bridport Sand Formation (BDS), Birdlip Limestone Formation (BLPL), Aston Limestone (ASLS), Salperton Limestone (SALS), and Fuller’s Earth Formation (FE). The only exception is the Charmouth Mudstone Formation, which was not present in any of the supplied boreholes as it is too deep to have been penetrated.

- The Birdlip Limestone Formation has been logged to Member level, distinguishing Leckhampton Member, Crickley Member, Cleeve Cloud Member, Scottsquar Member. Its uppermost Harford Member is absent hereabouts.
- The ‘Pea Grit’ and ‘Lower Limestone’ subdivisions of the Crickley Member are also distinguishable. Karstification and meter-scale voids are common, particularly at the top of the ‘Pea Grit’ unit, as evidenced from core loss, zones of very low density, sharp peaks in caliper logs, dark shadow on optical logs (i.e. 64-66m in BH400; 26-27m in BH418). These features may be due to cambering or dissolution or a combination of both. The ‘Pea Grit’ is variably ‘rubbly’ and geotechnically a weaker rock than the Oolite limestones above and below it, and it has ‘poorer’ rock mass quality (so expect variation in rock strength, RMR and Q values).
- The Aston Limestone Formation is thin (c.1m) and variably sandy in the project area.
- The Upper Trigonia Grit (UTG) and Clypeus Grit (CG) Members of the Salperton Limestone Formation are present and generally distinguishable. The Clypeus Grit is distinguishable in core/ hand specimen by the presence of orange-coated peloidal grains, while the Upper Trigonia Grit by large thick ‘ribbed’ Trigonia bivalve shells.
- The bases of the Upper Trigonia Grit Member, Leckhampton Limestone Member and Marlstone Rock Formation display a distinct gamma-ray signal (peak) in the geophysical logs. This will aid identification and correlation of these unit boundaries between boreholes. The Bridport Sand Formation also has an elevated gamma-ray signal, probably caused by the high abundance of mica grains (potassium).
- Borehole #224 is affected by relict to recent deep-seated landslide movements that involve rotation of the Bridport Sand Formation strata down to c.19m, and quite possibly some deeper rotation of the bedding in the Whitby Mudstone Formation down to c.40m depth (based on several tentative shear zones identified during the BGS check logging – see Tables and Appendix C for example photo).
- There is commonly a c. 2m thick ‘black/dark grey shale’ unit at the top of the Bridport Sand Formation just below the harder Leckhampton Member limestone. This ‘shale’ (noted by Cox and Sumbler, 2002) somewhat resembles the medium and dark grey mudstone of the Whitby Mudstone Formation, but before interpreting it as such, the logger/mapper is encouraged to look carefully for laminated white and grey ‘stripy’ fine sands below it that will indicate the passage down into the Bridport Sand Formation proper.
- The Whitby Mudstone Formation is typically 60m thick in the area. However, the thickness in borehole #224 is only 50m. This reduced thickness may be due to the local effects of extension associated with deep-seated rotational landsliding on the Cotswolds escarpment.
- The Marlstone Rock Formation is a distinctively very-strong (hard) limestone below the basal belemnite-rich ‘Cephalopod Beds’ of the Whitby Mudstone Formation. The Marlstone Rock, although thin, provides a key marker bed for correlation purposes to infer regional structural trends (bedding dip, faults, and folds) and will be useful for drawing accurate cross sections through landslipped ground and inferring sense of movement and throw on faults.

Appendix A – Register of observations, suggested changes, and Member-level interpretations

Table 7 Borehole stratigraphical summary DSRC #400 – Member level

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Member (Formation-member code)	Comments Suggested changes to GEL draft logs in red
E:394666, N: 213848, Ground Level = 267.95m aOD (near Birdlip Quarry)				
13.31	13.31	254.64	Fuller's Earth Formation (FE)	Khaki green firm silty clay/clayey silt/ to very weak mudstone. Moderate gamma signal. Note Gamma signal suppressed in top 8.1m due to plain steel casing. Distinct colour and texture change on Image log.
8.19	21.50	246.45	Clypeus Grit Member (SALS-CG)	Limestone, orange-coated ooids are distinctive feature in hand specimins. Boundary taken at base of fragments of reworked oolitic limestone in mudstone. 21.3m-21.6m core missing from box so boundary taken/ interpreted from Image log.
2.67	24.17	243.78	Upper Trigonia Grit Member (SALS-UTG)	Limestone, very poorly sorted (well-graded), orangey, with abundant large thick-ribbed Trigonia bivalve shells. Gamma peak at top.
0.83	25.00	242.95	Aston Limestone Formation (ASLS)	Sandy, shelly and muddy limestone, yellow, variable. 0.04m of white limestone pebbles on grey mud at base.
12.70	37.70	230.25	Scottsquar Member (BLPL-SQAR)	Ooidal limestone, good grainstone, lime-muddy and brachiopod-rich at base. Sparry calcite between rounded grains makes it strong. Generally low Gamma but may have Gamma peak at base where muddy. Grey colour between 32 and 36m. Packstone with clusters of articulated brachiopods is a distinctive feature.

25.90	63.60	204.35	Cleeve Cloud Member (BLPL-CLCL)	Uniform, Strong, white grainstone (no/rare whole shells) 'Devil's Chimney Oolite' (c.10.50m thick, depth base 48.20m, very low Gamma.) resting on white and orange shell-detrital 'Fiddlers Elbow Limestone' of *D.C. Mudge 1978* (c.15.40m thick, slightly raised Gamma).
11.20	74.80	193.15	Crickley Member (BLPL_CRKY)	'Pea Grit' (c.5.84m thick), abundant disc-shaped oncoids 63.6m through to about 69.5m, rests on 'Lower Limestone' (c.5.36m thick). 'Pea Grit' commonly rubbly and karstified with frequent large 0.1m to >1m width voids, particularly towards top e.g. 64-66m (sudden low on density log). Generally low Gamma. Lower Limestone has infrequent oncoids; unit boundary taken where oncoids become frequent. Water Table at 70.85m depth in image log.
2.32	77.12	193.15	Leckhampton Member (BLPL-LECK)	Strong, grey (base) becoming ferruginous /orange limestone with occasional orange silt-infilled pockets. Natural Gamma rises at base. Calcareous.
+13.80	+90.30	Base not proven	Bridport Sand Formation (BDS)	Frequent white/grey interlaminations of micaceous fine sand and silt. 'Black shales' (thinly-laminated grey mudstone) of *Cox and Sumbler, 2002* at top looks like Whitby Mudstone, but is not. Moderately high Gamma signal (probably due to Potassium in micas), BGS loggers note calcareous and micaceous fine-SANDSTONE at top (not SILTSTONE as suggested in GEL draft log) Not Whitby Mudstone Formation (WHM).

Table 8 Borehole stratigraphical summary DSRC #418 – Member level

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Member (Formation-member code)	Comments Suggested changes to draft GEL logs in red
E: 393132, N: 216419, Ground Level = 272.25m aOD (Crickley Hill Country Park)				
1.20	1.20	271.05	HEAD	Brown clay
c.21.8	Approx. 23.00	249.25	Scottsquar Member (BLPL-SQAR)	Strong, white, ooidal limestone, good grainstone, lime-muddy and brachiopod-rich at base. Sparry calcite between rounded grains makes cement strong. Generally low Gamma, but may have Gamma peak at base where muddy/marly. Packstone with clusters of articulated brachiopods is a diagnostic feature. Base depth based on 14m thickness in *Mudge 1978a&b*. Possibly some Aston Limestone Formation (ASLS) at top.
19.1	42.1	230.15	Cleeve Cloud Member (BLPL-CCL)	Uniform, Strong, white grainstone (no/rare whole shells) 'Devil's Chimney Oolite' white, strong to very strong, (c.11.90m thick, depth base c.34.90m, very low Gamma.) resting on white and orange shell-detrital 'Fiddlers Elbow Limestone' of *D.C. Mudge 1978* (c.15.40m thick, low but slightly raised Gamma compared with more pure oolite above). 'Strong' from 35.85m.
14.36	56.46	215.79	Crickley Member (BLPL-CRKY)	'Pea Grit' (c. 7.55m thick), abundant disc-shaped oncoids, rests on 'Lower Limestone' (c. 6.81m thick). 'Pea Grit' commonly orange, rubbly and karstified throughout with frequent large 0.1m to >1m width voids seen in image log backed up by Caliper log. Generally low Gamma. Gamma spike between 42m and 43m indicates clay, not seen in core so could have been disturbed by drilling process.

				'Lower Limestone' has infrequent oncoids and karstified throughout (seen on image log and low density peaks); unit upper boundary taken where oncoids become frequent (i.e. incoming 'Pea Grit'). 51.88-52.10m remnants of a clay band with polished surfaces. Gamma peaks. Could be karst infill soil. 53.90-54.30m sub-vertical clay-filled discontinuity, brown, euhedral ?calcite crystals grown on upper and lower surfaces. Gamma peak. Interpreted as possible fault zone/gouge or infilled/in wash into Gull/Karst void? Could date calcites/clay if younger than c.500ka. See photo in Appendix C. Rest water level at 56.4m depth in image and fluid logs. Image log murky and poorer quality below water table.
2.41	58.87	213.38	Leckhampton Member (BLPL-LECK)	Strong, becoming very strong at base, grey (at base) and ferruginous /orange limestone, with occasional orange silt-infilled pockets. Natural Gamma rises at base. Density increase relative to 'Lower Limestone' unit above. Sharp lower boundary.
+2.63	TD 61.5	Base not proven	Bridport Sand Formation (BDS)	Frequent white/grey interlaminations of micaceous fine sand and silt. 'Black shales' (ex. weak, thinly-laminated, cross-laminated, grey mudstone, slightly micaceous, non-calcareous) of *Cox and Sumbler, 2002* at top looks like Whitby Mudstone, but is not. Moderately high Gamma signal (probably due to Potassium in micas). BGS loggers note Strong, orangey-brown, calcareous, micaceous SANDSTONE between 61m to 61.5m (not SILTSTONE as suggested in GEL draft log)

				Not Whitby Mudstone Formation (WHM as suggested in GEL draft log).

Table 9 Borehole stratigraphical summary DSRC #109 – Member level

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Member (Formation-member code)	Comments Suggested changes to draft GEL logs in red
E: 393208, N: 215995, Ground Level = 233.00m aOD. Located on eastern roadside on approach to The Air Balloon)				
2.45	2.45	230.55	HEAD and Regolith	1.2 -2.45 is probably regolith of BLP.
+15.55	Approx.18.00	215.00	Crickley Member (BLPL_CRKY)	'Pea Grit' (c. +6.35m thick, base at c.8.80m), abundant coarse-grained (2-5mm) dia. disc-shaped oncoids, rests on 'Lower Limestone' (c. 9.2m thick, base 18.0m). 'Pea Grit' commonly orange, rubbly, and karstified throughout with frequent large 0.1m to >1m width voids seen in image log and caliper log. Generally low Gamma. 'Lower Limestone' has infrequent oncoids and karstified throughout (seen on image log and low density peaks); unit upper boundary taken where oncoids become frequent (i.e. incoming 'Pea Grit').
2.95	20.95	212.05	Leckhampton Member (BLPL-LECK)	Strong, becoming very strong at base, grey (at base) and ferruginous /orange limestone, with occasional orange silt-infilled pockets. Natural Gamma and density increases at base relative to 'Lower Limestone' unit above. Calcareous – reacts to a few drops of 10% HCL acid. Black fossil wood fragments. Sharp lower boundary.
29.05	c.50.00	183.00	Bridport Sand Formation (BDS)	Frequent white/grey interlaminations of micaceous fine sand and silt. (diagnostic

				feature is frequent wisps of fine-sand and silt) 20.95 – 22.15m ‘black shales’ of *Cox and Sumbler, 2002. Ex*. weak, thinly-laminated, cross-laminated, grey mudstone, slightly micaceous, non-calcareous) at top looks like Whitby Mudstone, but is not. Moderately high Gamma signal (probably due to Potassium in micas). Lower boundary gradational. Rest water table at approx. 24.60m in optical and fluid logs. From 24.8m downwards GEL logs say WHM, but BGS interprets as BDS to approx. 50.00m. Lower density from 39m due to mudstone.
+55.00	+105.00	Base not reached	Whitby Mudstone Formation (WHM)	Grey silty mudstone. Wisps of fine sand becoming rare. 51.82-51.89m Very strong pyritised sandstone band. From 57.8m becomes brown with black phosphatic ooids (fine sand size) 58.30-59.40m grey mudstone 59.50-59.70m brown with black phosphatic ooids (fine sand size) 73.90m Ammonite fragments (ribbed) 74.84m Ammonite in grey mudstone 98.00 – 98.5m micro faults with slickensides and sight offset (could be related to valley bulging?)

Table 10 Borehole stratigraphical summary DSRCOH # 308– Member level

Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Member (Formation-member code)	Comments Suggested changes to draft GEL logs in red
Ground Level = 271.35m aOD. No geophysical logs available.				
0.4	0.4		Top soil	Gravelly clay.
0.5	0.9	270.45	Clypeus Grit Member (SALS-CG)	Limestone, orange-coated ooids. Boundary taken at base of fragments of reworked oolitic limestone in mudstone.
2.65	3.55	267.80	Upper Trigonia Grit Member (SALS-UTG)	Limestone, very poorly sorted (well-graded), orange, with abundant large thick-ribbed Trigonia shells. Gamma peak at top.
0.9	4.45	266.90	Aston Limestone Formation (ASLS)	Sandy, shelly and muddy limestone, yellow, variable. 0.04m of white limestone pebbles on grey mud at base. Note Harford Member is absent.
14.40	18.85	252.50	Scottsquar Member (BLPL-SQAR)	Ooidal limestone, nice grainstone, marly or oyster-encrusted at base. Sparry calcite between rounded grains makes it strong. Generally low Gamma but may have Gamma peak at base where muddy. Packstone with clusters of articulated bivalves is a distinctive feature. Moderately strong, muddy/chalky, cream colour, at base.
24.28	43.13	228.22	Cleeve Cloud Member (BLPL-CLCL)	Uniform, strong, white grainstone (no/rare bivalves) 'Devil's Chimney Oolite' (c.14.6m thick, depth base 33.45m, very low Gamma.) resting on white and orange shell-detrital 'Fiddlers Elbow Limestone' of *D.C. Mudge 1978* (c.9.68m thick, base at 43.13m, slightly raised Gamma).
13.24	56.37	214.98	Crickley Member (BLPL_CRKY)	'Pea Grit' (c.7m thick, base at approx. 50.13), abundant disc-shaped oncoids, rests on 'Lower Limestone' (c.6.24m thick). 'Pea Grit' commonly rubbly and karstified with frequent large 0.1m to >1m width voids,

				particularly towards top. Generally low Gamma. Lower Limestone has infrequent oncoids; unit boundary taken where oncoids become frequent.
2.74	59.11	212.24	Leckhampton Member (BPL-LECK)	Strong ferruginous /orange slightly shell-detrital limestone with occasional orange silt-infilled pockets. Natural Gamma rises at base. Calcareous. Note the grey very strong limestone seen in other boreholes in this report is missing here.
>11.29	>70.40	Base not proven	Bridport Sand Formation (BDS)	Frequent white/grey interlaminations of micaceous fine sand and silt. 'Black shales' (3.49m of thinly-laminated grey mudstone, calcareous) of *Cox and Sumbler 2002* at top looks like Whitby Mudstone, but is not. Moderately high Gamma signal (possibly enhanced due to Potassium in micas). 59.45-60.00m lithology should be laminated SILT not CLAY on GEL log and top of unit should be raised 59.11m. 60.00-61.40m silty CLAY (not just CLAY). 61.4-62.0m Medium strong, weak after 62.0m. 62.10-62.60m bioturbated, non-calcareous. 62.60m-70.40 lithology is SILTSTONE, not MUDSTONE. 65.00m-66.4 light greenish grey siltstone with laminae of fine sandstone. 66.4-66.7 dark grey laminated silt and sand 66.7-70.4 light grey and white fine-scale bedding structures.

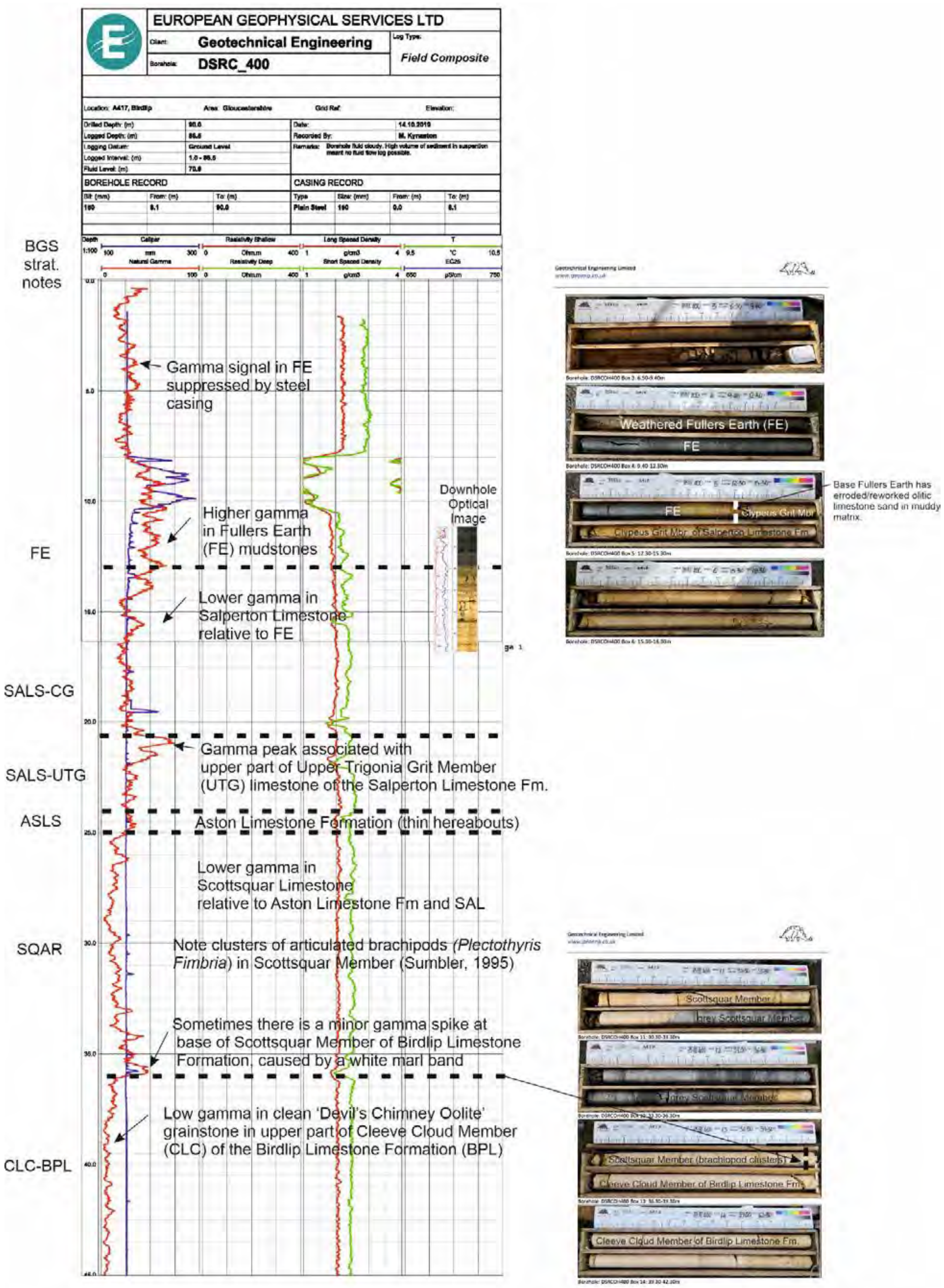
Table 11 Borehole stratigraphical summary DSRCOH # 224 – Member level

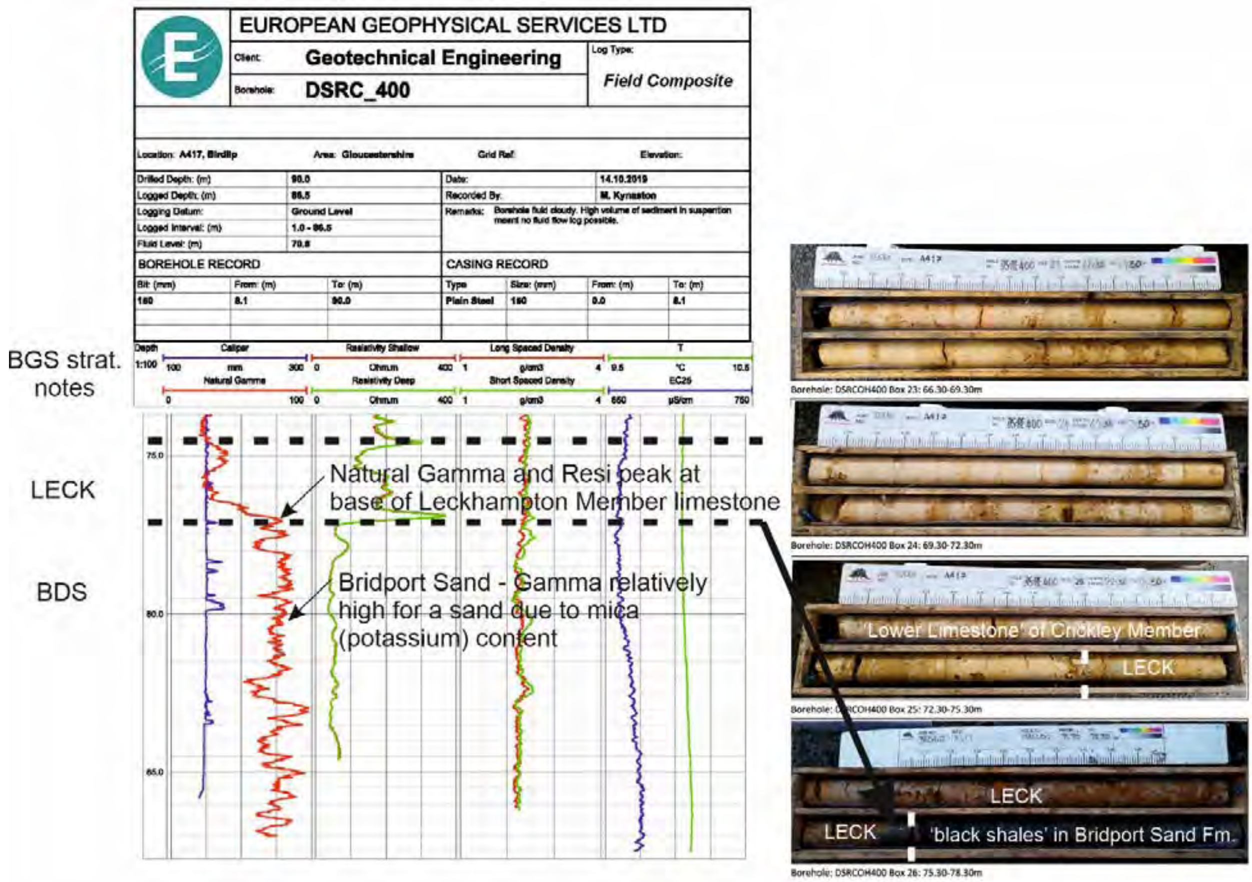
Apparent thickness (m)	Depth to base (m b.g.l)	Reduced level to base (m aOD)	Member (Formation-member code)	Comments Suggested changes to draft GEL logs in red
E: 392857.0, N: 215346.0 Ground Level = 226.85. Southern Cotswolds Escarpment on Landslipped ground				
0.60	0.60	226.25	MGR	
2.90	3.50	223.35	COLV & HEAD	Talus or Rubble (Limestone gravel/cobbles)
5.50	9.00	217.85	EARTHFLOW/Solifluction	Stiff clayey SILT (GEL descriptions are fine, could use 'SLIP' or 'EARTHFLOW/Solifluction' rather than 'COL')
10.00	19.00	207.85	SLIP - BDS	Laminated silt and sand, slipped, deep-seated rotational landslide *General note on use of 'COL' (Colluvium) – 'SLIP - BRIDPORT SANDS' may be more appropriate code. 5.00-8.78m EARTHFLOW incorporating weathered Bridport Sands materials and colluvium/solifluction. Below 8.78m is slipped/rotated bedrock materials. 8.78-19.00m ROTATIONAL LANDSLIDE affecting BDS. @9.04m very thin dark plastic clay (slip surface within mudflow/earthflow deposits) 9.00-9.90m bedding structure is orientated 25 deg. to horizontal. @16.5m bedding structure dip is orientated 10-15 degrees to horizontal. 19.25-19.35m 'limestone cobble' described in GEL log; BGS interpret this as a limestone bed. Use of 'MST' code on GEL logs is confusing as this is

				a lithology code not a stratigraphical code.
50.00	69.00	157.85	WHM	Laminated silty mudstone Possible (?relict) slip surfaces/shears down to c.41m depth @25.80m Ammonite @34.15m polished inclined surface (30 degree) 37.50-37.51m polished oblique fracture zone, rubbly angular broken mudstone fragments – ***possible slide surface*** 38.0 – 38.1 Possible slide surface/shear zone (See Photo in Appendix C) 39.80-40.90 agree that bedding structure is orientated 10 degree to horizontal. ***Possible basal (relict) slip surface?*** @65.65 bedding is horizontal (Probably not slipped). Ammonites are pink aragonite. 67.82-69.00m towards base of WHM the colour changes from dark grey to medium grey, indicated incoming of 'Cephalopod Limestone Beds'.
1.05	70.05	156.80	MRB	Limestone with pebbles (conglomerate) of brown sideritic siltstone at base (see photo). MRB is a key stratigraphical marker bed for understanding landsliding depth and structure along the Cotswolds escarpment.
>10.45	>80.50	> Base of formation not reached	DYS	Mudstone and siltstone. 71.00-72.90 note reduction halos around pods of sand. 75.30-76.15m Non-calcareous SANDSTONE, (not LIMESTONE as indicated on GEL log).

		76.15-80.00m is fine-SANDSTONE (not SILTSTONE as indicated on GEL log). 80.00-80.50 DYS to TD.

Appendix B – Correlation of lithostratigraphy with geophysical logs




EUROPEAN GEOPHYSICAL SERVICES LTD
Client: Geotechnical Engineering
Borehole: DSRC_400
Log Type: Field Composite
Location: A417, Birdlip
Area: Gloucestershire
Grid Ref:
Elevation:
Drilled Depth: (m) 90.0
Logged Depth: (m) 86.5
Logging Datum: Ground Level
Logged Interval: (m) 1.0 - 86.5
Fluid Level: (m) 70.8
Date: 14.10.2019
Recorded By: M. Kynaston
Remarks: Borehole fluid cloudy. High volume of sediment in suspention meant no fluid flow log possible.
BOREHOLE RECORD
Bit (mm) 150 From (m) 8.1 To (m) 90.0
CASING RECORD
Type Plain Steel Size (mm) 150 From (m) 0.0 To (m) 8.1
Depth 1:100
Caliper 100 mm 300
Natural Gamma 0 100
Resistivity Shallow 0 Ohm.m 400
Resistivity Deep 0 Ohm.m 400
Long Spaced Density 1 g/cm3 4
Short Spaced Density 1 g/cm3 4
T 9.5 °C 10.5
EC25 650 µS/cm 750
75.0
80.0
85.0
BGS strat. notes
LECK
BDS
Natural Gamma and Resi peak at base of Leckhampton Member limestone
Bridport Sand - Gamma relatively high for a sand due to mica (potassium) content
Borehole: DSRCOH400 Box 23: 66.30-69.30m
Borehole: DSRCOH400 Box 24: 69.30-72.30m
'Lower Limestone' of Crickley Member
LECK
Borehole: DSRCOH400 Box 25: 72.30-75.30m
LECK
LECK
'black shales' in Bridport Sand Fm.
Borehole: DSRCOH400 Box 26: 75.30-78.30m

Appendix C – Core photos

Figure 3 BH224 at 70.0m. Marlstone Rock (MRB). Very strong to strong grey limestone with distinctive rounded sideritic siltstone pebbles at base.

Figure 4 BH DSRC224: Possible shear zone in Whitby Mudstone Formation mudstone at 38.0-38.1m. Note brown small gravel-sized litho-relicts of ferruginous siltstone in upper half of core and dark grey laminated mudstone in lower half.

Figure 5 Typical Whitby Mudstone Formation (WHM) weak laminated dark grey mudstone with bivalve and ammonite (pink aragonite) fossil content.

Figure 6 BH400. Close-up photo of typical Bridport Sand Formation (BDS) with grey fine-sand with subordinate white whispy sand laminae. Very weak to weak rock.

Figure 7 BH418: Lower run showing sharp contact between 'very strong' grey limestone at base of Leckhampton Member (LECK-BLPL) with underlying 'weak' dark grey laminated 'black shale' mudstone unit at top of Bridport Sands Formation.

Figure 8 BH400. Lower run showing contact between 'strong', grey, limestone at base of Leckhampton Member (LECK) and weaker dark grey interlaminated mudstone and fine sands

representing the 'Black Shale' unit at the top of the Bridport Sand Formation (BdS). Upper run shows typical ferruginous, slightly sandy, Leckhampton limestone.

Figure 9 BH308. Middle run showing contact between top Leckhampton limestone (LECK) and approximate base of the 'lower limestone' unit of the Crickley Member (CRKY-BLPL) of the Birdlip Limestone Formation. Arrows indicate way-up with top of core on right hand side. Core is approx. 100mm (4”) diameter.

Figure 10 BH418 at 54.3m. Upper run shows red-brown stiff clay gauge with rhomboidal (probably calcite) crystals formed in wall rock. Interpreted by BGS as possible fault zone or in-washed palaeo-karst feature. Lower run is ferruginous orange 'strong' limestone typical of the upper part of Leckhampton Member (LECK-BLPL).

Figure 11 BH308. Approximate boundary (placed at 50.13m) between approximate base of rubbly 'Pea Grit' limestone and top of more competent/strong 'lower limestone' unit of Crickley Member (CRKY-BLPL). Arrow shows way-up/points to top of core. Lower boundary of 'Pea Grit' taken as were the distinctive oncoidal-rich limestone beds become more common than the strong white micrite limestone.

Figure 12 BH308. Close up photo of typical 'Pea Grit' unit in upper part of Crockley Member (CRKY); moderately weak limestone rock, packed full of medium to coarse sand-sized disk-shaped oncoids (1-5mm dia.), rubbly rock mass, loosely packed with large voids (indicated by core loss and confirmed by geophysical logs), variable strength, poorly cemented. Scale is in cm.

Figure 13 BH308. Boundary (at 43.13m) between top of 'Pea Grit' unit (CRKY-BLPL) and shell-detrital limestones of the 'Fiddler's Elbow Limestone' unit in the lower part of the Cleeve Cloud Member (CLCL-BLPL).

Figure 14 BH308. Close up photo of the typically light brown shell-detrital 'Fiddlers Elbow' limestone (packstone) at the base of the Cleeve Cloud Member (CLCL-BLPL). Scale bar is in cm.

Figure 15 BH308. Upper run is gradational boundary between light brown shell-detrital 'Fidder's Elbow' limestone and overlying white, ooidal, 'Devil’s Chimney Oolite' (grainstone) in the upper part of the Cleeve Cloud Member at the top of the Birdlip Limestone Formation. Lower two runs are typical Devil’s Chimney Oolite’.

Figure 16 BH308. Sharp boundary (at 18.85m) between 'Devil's Chimney Oolite' at upper Cleeve Cloud Member and the cream limestones (grainstone) of the Scottsquare Member at top of Birdlip Limetone Formation. ‘Sq’ at 18.85m marks a weaker marly layer coincident with a gamma peak in the downhole geophyscial logs. Diagnostic clusters of Brachiopods can be seen in a freshly broken surface on the left hand side at around 18.5m. Middle and lower runs are typical Scottsquare Limestone.

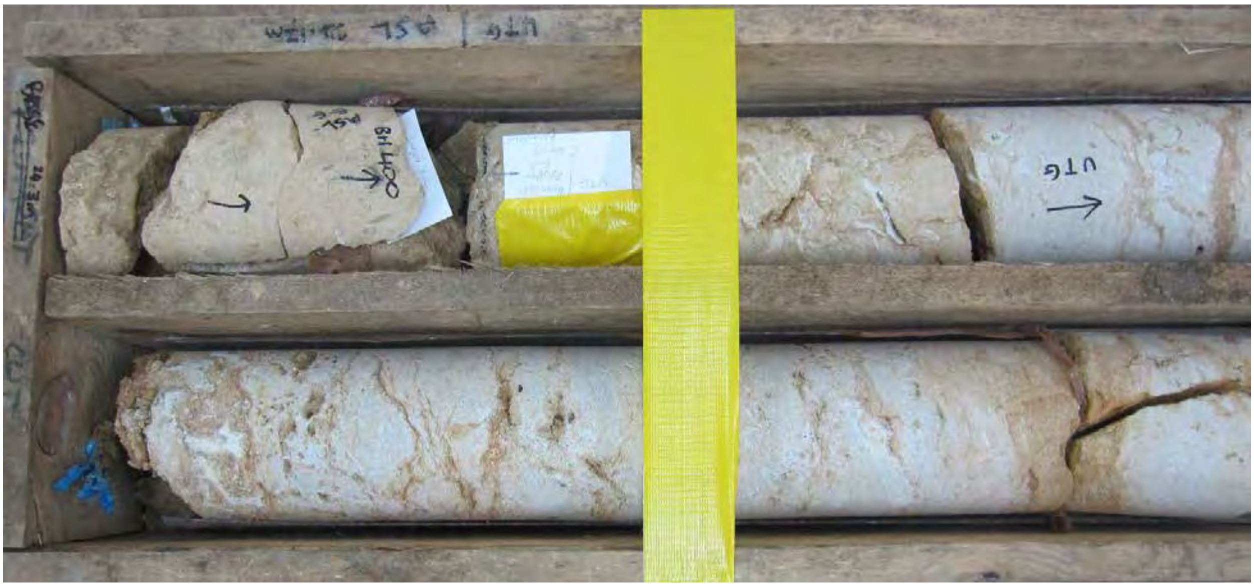


Figure 17 BH400. Upper run shows boundary between light brown slightly sandy Aston Limestone Formation (ASLS-GG) with base of Upper Trigonia Grit of the Salperton Limestone Formation (SALS-UTG) with distinctive thick (5mm) white whips of Trigonia bivalve shells.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

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Appendix D Surface geophysics interpretation

D.1 Introduction

D.1.1 Purpose of this appendix

D.1.1.1 This appendix was produced to describe the geophysical surveys that were undertaken and presents an interpretation of the results.

D.2 Geophysical survey

D.2.1 Survey intention

D.2.1.1 The work was designed to complement the intrusive ground investigation to provide further information on the geology and ground conditions with focus on the identification of the following:

- Confirmation of fault locations namely the Shab Barn, Shab Barn Hill and the Stockwell faults.
- Strata boundaries.
- Variability and thickness of the mass movement deposits within the Crickley Hill valley.
- Potential voids in the form of gulls within the Inferior Oolite Group near the escarpment.

D.2.2 Survey approach

D.2.2.1 The geophysical survey consisted of an integrated survey approach utilising:

- electromagnetic (EM) ground conductivity measurements.
- electrical resistivity tomography (ERT) profiles.
- seismic P and S-wave refraction profiles.
- Multichannel Analysis of Surface Waves (MASW) profiles along selected resistivity lines.

D.2.2.2 The fieldwork was carried out during October to November 2019 and January 2020 and was split into a trial zone and a further four zones across the site. The geophysical survey was carried out by Terradat on behalf of Geotechnical Engineering Limited and findings are presented in the Phase 2A factual report [33]. The conductivity mapping zones, and the survey lines are presented on the Exploratory Hole Plans (HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000001 to 000006) in Appendix J, in combination with the historical, Phase 1 and Phase 2A ground investigations.

D.3 Results and interpretation

D.3.1 General

D.3.1.1 The interpretation of the geophysical data presented by Terradat [33] has been used to inform the ground model interpretation. The interpretation presented by Terradat has used the available ground investigation information at the time of the surveys. As such the information available was limited and all of the ground investigation information used within the GIR has been used to check the initial interpretation and is presented as part of this appendix.

D.3.1.2 Selected geophysical lines overlayed with the exploratory hole information are attached to this Appendix to illustrate the interpretation presented by Terradat and highlight any suggested changes to the Terradat interpretation.

D.3.1.3 The following presents the interpretation used to inform the location of the faults, stratigraphy and potential for voids.

D.3.2 Faults

Shab Hill Fault – Ch 1+750 to 2+100 (main cut)

D.3.2.1 The fault is traceable as a linear northwest-southeast feature of slightly higher conductivity (compared to the limestone surrounding the feature) in the ground conductivity mapping in Zone 1. This is broadly consistent with the location of the fault shown on the BGS published mapping (Figure D-1). The data suggests a possible deterioration in the condition of the limestone around the fault Zone due to the lower conductivity and the presence of more head deposits (high conductivity) material towards the north.

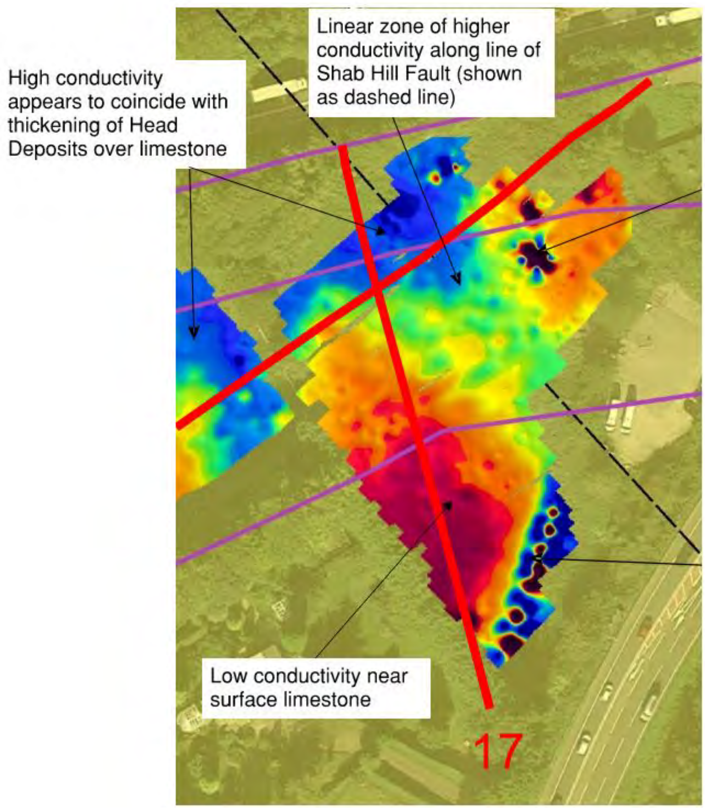


Figure D-1 Extract of Zone 1 electromagnetic survey

D.3.2.2 The Shab Hill Fault in this area is identified on ERT lines 17 and 19 (refer to Section Line 19 for ERT line 19) where it is identified based on the following features:

- A reduction in S wave velocity towards the east (potentially poorer quality rock mass)
- Decrease in density

D.3.2.3 The fault is potentially identified to the northern end of ERT line 17 as a linear zone of lower resistivity material with depth separating higher resistivity material. The presence of the fault cannot be identified clearly in ERT line 16 located to the north of the scheme.

Shab Hill Fault – Ch 3+000 to 3+500 (Shab Hill junction)

D.3.2.4 The Shab Hill Fault has not been identified as part of the conductivity surface mapping (refer to Figure D-2) but has been identified on ERT lines 21 and 22 (refer to Section Line 22 for ERT line 22). The fault in both the lines is identified based on the following evidence.

- a linear zone of lower resistivity material with depth separating higher resistivity material (limestone) either side.
- The zone corresponds to a sharp jump in S and P wave velocities to the north east.

D.3.2.5 The fault was not identified in ERT line 23 or ERT line 24 and is considered to run further north in relation to the northern end of both these lines.

Shab Hill Barn Fault – Ch 3+000 to 3+500 (Shab Hill junction)

D.3.2.6 The fault is traceable in the EM mapping in Zone 3 (Figure D-2), and supports the BGS published mapping of a northwest to southeast trending fault.

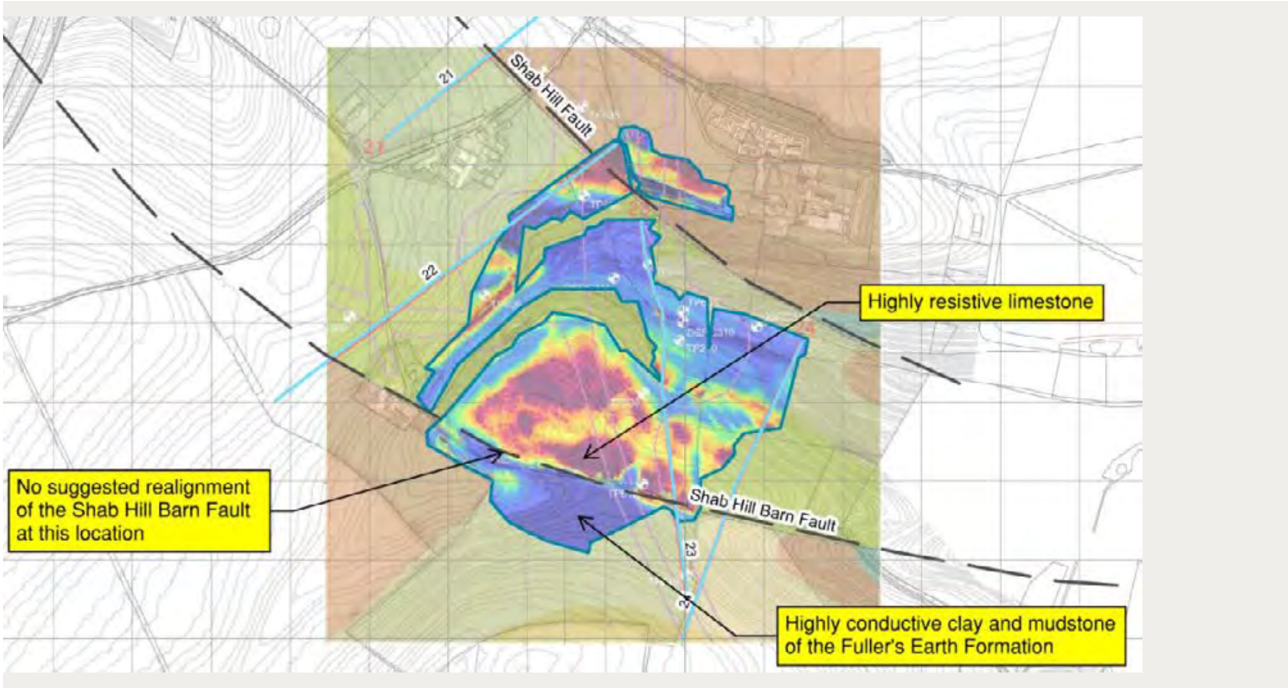


Figure D-2 Electromagnetic mapping survey at Shab Hill

D.3.2.7 The Shab Hill Barn Fault is identified as a linear zone of lower resistivity material with depth separating higher resistivity material either side on ERT lines 22 (refer to Section Line 22 for ERT line 22) or as lower resistivity material adjacent to higher resistivity material in ERT lines 23 and 24.

Churn Valley Fault – Ch 3+000 to 3+500 (Shab Hill junction)

D.3.2.8 An additional fault (termed the Churn Valley Fault) was identified within the study area. The Churn Valley Fault was observed on ERT lines 22 and 23 in between the Shab Hill and the Shab Hill Barn faults.

D.3.2.9 It has been identified based on an abrupt change from low resistivity material (interpreted as Fuller's Earth Formation) towards the north and high resistivity material (interpreted as limestone associated with the Great Oolite Group) to the south (refer to Section lines 22 and 23).

D.3.2.10 There is some discrepancy with the interpretation on Section line 22 (for ERT line 22) as the Fuller's Earth Formation has been identified to the north and south of the Churn Valley Fault but on the south a highly resistive material with depth has been recorded. There is no evidence within the borehole logs to suggest significant quantities of limestone in the Fuller's Earth Formation to the south of the fault.

D.3.2.11 The fault is traceable in the EM mapping in Zone 3 (Figure D-2), and appears to trend northwest to southeast where a lineation of low conductivity material is adjacent to high conductivity material along the axis of the valley.

Stockwell Fault (Ch 4+750)

D.3.2.12 The Stockwell Fault has been identified from the surface conductivity mapping (refer to Figure D-3) as a northwest southeast linear feature between an area of relatively low conductivity to the north (interpreted as limestone) and an area of higher conductivity to the south (interpreted as Fuller's Earth Formation.

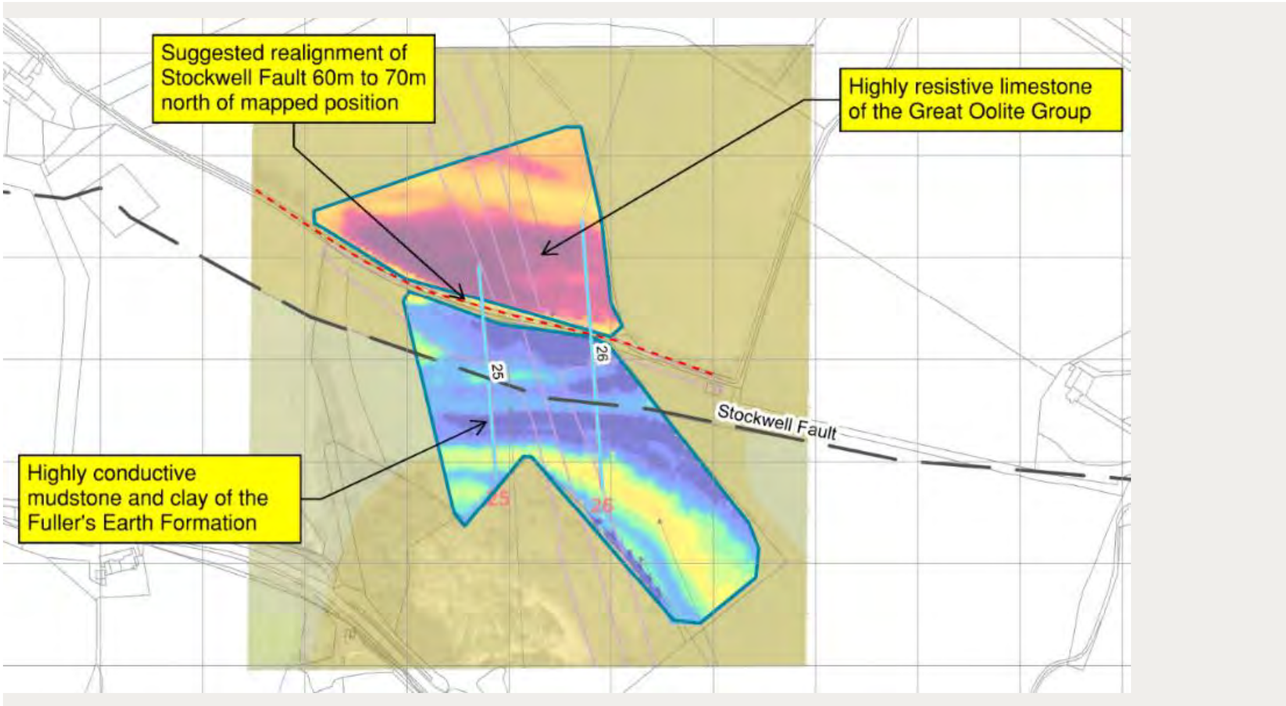


Figure D-3 Electromagnetic mapping survey at Stockwell

D.3.2.13 The interpreted fault location is approximately 60 to 70m north of the BGS published location of the fault (Figure D-3).

D.3.2.14 The fault has been identified on ERT lines 25 and 26 separating material of high resistance to the north (interpreted as Great Oolite Limestone) from material of lower resistance to the south (interpreted as the Fuller's Earth Formation) (refer to line Section 25 for ERT line 25).

D.3.3 Strata interpretation

D.3.3.1 The suite of surface geophysical surveys has been "truthed" against the intrusive ground investigations to assess if the geophysical surveys can provide information on the broader stratigraphy away from the exploratory holes. Table D-1 presents the main features identified in the geophysical surveys applicable to the strata types across the scheme.

Table D-1 Summary of surface geophysical survey strata interpretation

Strata	Geophysical features	Representative values to characterise strata
Mass movement deposits (MMD)	Crickley Hill (Zone 2 and trial zone) Conductivity mapping conducted as part of the trial zone on the southern slope from ch 1+000 to 1+500 typically mapped conductivities from 60 to 90 mS/m with and are of low conductivity of around 30mS/m within the slope. Based on the exploratory holes within the mapping extent the conductivities of 30mS/m correlate to granular material and the typical range to cohesive material. Following resistivity trends observable: • MMD typically recorded resistivity range from 25 to 35ohm.m and relate to cohesive MMD based on exploratory holes. • Within typical range of cohesive material low resistance zones through the profile (some tie up with water strikes in boreholes but difficult to interpret from borehole logs as what it represents (check against PI and NMC data plots)). • On southern slopes low resistance (up to 20 ohm.m) zones within slip mass towards base of the slope (area of soft soil logged in exploratory holes along Normans Brook) and within middle section of the slope in ERT-5 (refer to Section Line 5). • High resistance (50 to 300 ohm.m) (up to 5m deep and 5 to 50m in length) identified within both northern and southern slopes. Thicker zones identified towards upper sections of slopes (both northern and southern slopes). Interpreted as inclusions of granular material or blocks of limestone within the slope. MASW stiffness range 100 to 300m/s (cohesive and granular) S wave velocities typically <500m/s with thicknesses ranging from 10 to 25m. This agrees well with the logged thicknesses of the MMD in the exploratory holes. Considered to provide a good degree of confidence of base of MMD across northern and southern slopes. <u>Shab Hill</u> Potential MMD approaching Churn Valley Fault and on northern side slopes of Churn Valley – low resistivity (0 to 15 ohm.m) up to 5m thick. Low stiffness (100 to 140m/s) on MASW over similar thickness range (refer to Section Line 23). ERT 23 near to exploratory holes TP6030 and DSRC311 that encountered MMD over similar thickness range. S wave velocities generally <300m/s in upper 3m	Crickley Hill Conductivity 60 to 90 mS/m (cohesive) with 30mS/m inclusions (granular material) Resistivity 25 to 50 ohm.m (cohesive) MASW 100 to 300 m/s S wave <500m/s Shab Hill <u>Resistivity</u> Up to 15 ohm.m <u>S wave</u>

Strata	Geophysical features	Representative values to characterise strata
	Difficult to determine on southern slope – potential for cambered block (refer to Great Oolite limestone below)	<300m/s
Head deposits	Main cut (Zone 1) The MMD appears to increase in thickness towards the valley axis, which is also identified on several of the exploratory hole logs (thickening from less than 1m to 2.5m). Material identified as a clayey gravel to gravelly clay on borehole logs appears to coincide with increased conductivity (refer to Figure D-1) of 60mS/m and lower resistance ranging from 90 to 150 ohm.m (refer to Section Line 19) MMD associated with Great Oolite Group – limestone and Fuller's Earth Formation are difficult to distinguish on the geophysical sections (ERT lines 23 and 24). Any observations in relation to the conductivity and resistivity applied to the strata section below rather than the MMD.	IOG – head <u>Conductivity</u> 60mS/m <u>Resistivity</u> 90 to 150 ohm.m
Great Oolite Group - limestone	Identified in Zones 3 and 4 (Shab Hill to Stockwell) and identified with a good degree of certainty (confirmed by exploratory holes) using conductivity mapping (refer to Figure D-2 and Figure D-3) and ERT lines (refer to Section Lines 22, 23 and 25) Conductivity mapping shows a difference in conductivity of the limestone between the two zones. Higher conductivity (18 to 60 mS/m) around Stockwell compared to around 20mS/m at Shab Hill. The higher conductivity observed is attributed to the absence of GOG limestone and the presence of the underlying Fuller's Earth t surface over a more extensive area than currently shown on the published geological mapping towards the south of scheme. This is supported by evidence from the exploratory holes undertaken in this area. Resistivity for GOG limestone appears to be around 150 to 500 ohm.m for ERT lines in both zones. Within Shab Hill, potential for cambered GOG limestone on southern slope of Churn valley evidenced by higher resistance blocks thinning/draping down the valley slope (refer to ERT line 24).	<u>Conductivity</u> 20 to 60mS/m (20mS/m at Shab Hill) <u>Resistivity</u> 150 to 500 ohm.m
Great Oolite Group - Fuller's Earth Formation (FEF)	Identified in Zones 3 and 4 (Shab Hill and Stockwell) and identified with a good degree of certainty (confirmed by exploratory holes) using conductivity mapping (refer to Figure D-2 and Figure D-3) and ERT lines (refer to Section Lines 22, 23 and 25). Conductivity mapping shows difference in conductivity between the two zones. Higher conductivities of approximately 140 to 210 mS/m around Stockwell compared to approximately 40 to 90 mS/m at Shab Hill.	<u>Conductivity</u> 140 to 210mS/m (south of Shab Hill to Stockwell) (40 to 90mS/m within Churn Valley)

Strata	Geophysical features	Representative values to characterise strata
	GI to south of Shab Hill has encountered FEF predominantly at surface with an upper weathered horizon that is likely to be associated with the higher conductivity. The stiffness from the MASW is consistently low over this extent (100 to 140m/s) consistent with the presence of the weathered upper surface. At Shab Hill, within the Churn Valley, lower conductivity areas have been identified associated with FEF within the valley side slopes, where overlying material has potentially reduced the weathering impact. To the northwest of the Churn Valley higher conductivity zones have been identified towards the crest of the valley slope where the FEF is likely to be exposed at surface. The resistivity of the FEF was recorded at around 10 to 20 ohm.m for ERT lines in both zones. Potentially slightly higher resistances were recorded when the FEF was underlying the GOG limestone, potentially attributed to the lower degree of weathering of these materials (increases to around 10 to 50 ohm.m) – refer to Section Line 22 (from ERT line 22). GI information with depth through the FEF lacking south of Stockwell. Seismic survey in particular S-wave velocities provide an indication of the base of FEF (S wave velocities appear to change from around 400 to 600m/s to >1000m/s at this boundary). (Note: There is a potential discrepancy for ERT line 22 with FEF to the south of Churn Valley Fault where the typical resistivities do not match the logged description of material encountered. Boreholes have recorded predominantly mudstone but resistivity increases rapidly with depth from 90 to 400 ohm.m. The S wave velocities are also higher than the typical values proposed for the FEF.	Resistivity 10 to 20 ohm.m S-wave South of Stockwell <600m/s
Inferior Oolite Group	Encountered from ground level in Zone 1, based on geological mapping and exploratory holes. Conductivity surface mapping indicates a variation in IOG away from the escarpment and towards Shab Hill Fault (refer to Figure D-1). Conductivity is typically circa 40mS/m but this increases to around 50mS/m near the identified fault and up to 60mS/s to the north towards the valley axis. Possibly linked to increase in thickness of the MMD, in this area, as also indicated within a number of the exploratory holes. ERT lines consistently indicate resistivity varies from 150 to 1000 ohm.m (refer to Section Lines 17-18 and 19). Lines generally show higher resistivity limestone associated with higher ground with drop in resistivity approaching the valley axis. ERT19 (running parallel to scheme) shows a general variability of resistivity within the upper 5m with low (90 to 150 ohm.m) and high areas. This is interpreted to be associated with areas of	Conductivity Typically 40mS/m (approaching fault 60mS/m) Resistivity 150 to 400ohm.m (variability in upper 5m) High resistance with depth towards west and as ground level rises to

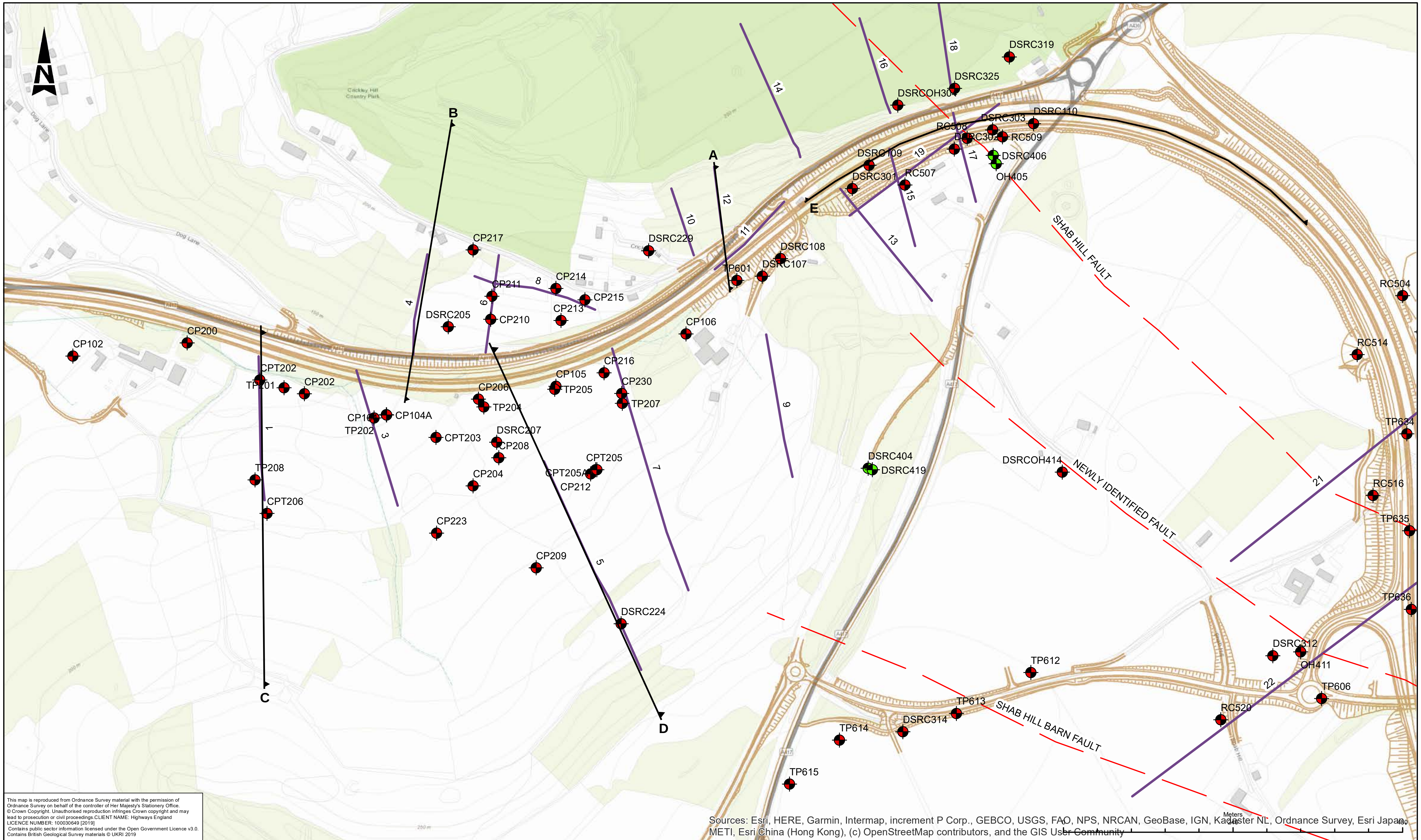
Strata	Geophysical features	Representative values to characterise strata
	greater thicknesses of MMD. ERT 19 typical suggests resistivity of 200 to 300 ohm.m with highly resistive blocks (400 to 1000 ohm.m) to the West. Seismic velocities (S wave) for the upper 8 to 10m range from 500 to 900m/s below which S-wave velocities increase to >1000m/s. Approaching Shab Hill Fault, the S-wave velocities of the material below 8m reduces to around 800m/s. The variations in the S wave velocities provides a good indication of changes in the rock quality and is consistent with the findings from exploratory holes of lower RQDs and increased fractures towards the faults. Shab Hill IOG identified on ERT lines (refer to Section Lines 22 and 23). Resistivity range 150 to 200 ohm.m (possible transition at base of FEF to IOG?)	north and south (400 to 1000 ohm.m) <u>S-wave</u> Upper 8 to 10m 500 to 900m/s Below which >1000m/s (approaching fault to east all around 800m/s)
Lias Group	<u>Crickley Hill (Zone 2 and trial zone)</u> The ERT sections show a range in resistivity within the Lias that can be similar to the MMD (ranging from 10 to 40 ohm.m). Based on the exploratory holes the upper surface of the Lias Group is cohesive and would have a similar resistivity response to the MMD. The MASW sections suggest a higher S wave velocity (representing a stiffer response) within the Lias (range from 350 to 600 m/s). However, the response is very similar to that of the overlying MMD. The seismic sections provide a reasonably good correlation with the top of the Lias Group. S wave velocities >500m/s are associated with the Lias Group. The top of the Lias Group is predicted to occur at around 15 to 20m below ground level. An exception to this is line 12 where a stepped profile in the Lias Group is predicted where the depth to the Lias Group on the down slope extent of the line is around 28m below ground level. There is no borehole in this area to validate this interpretation and will be reviewed as part of the Annex A Addendum. <u>Within the escarpment (main cut) (Zone 1)</u> The Lias Group was not identified in lines for Zone 1 – It is likely that the IOG masks the response at depth for resistivity and seismic S-wave velocities.	<u>Resistivity</u> Not conclusive – similar to MMD <u>MASW</u> 350 to 600m/s <u>S wave</u> >500 m/s

D.3.4 Gulls

D.3.4.1 The geophysical survey data do not provide any conclusive evidence for the presence of gulls or dissolution voids. The electromagnetic surface mapping in Zone 1 has recorded a high conductivity linear feature towards the north west of the mapping area but no obvious resistivity contrast has been identified on ERT 19 that also crosses this feature.

D.3.4.2 Further consultation with the landowner regarding private utility services along this extent in addition to additional trial trenching is proposed as part of the further ground investigation stages as defined in the Annex A Addendum.

Appendix E Selected cross sections

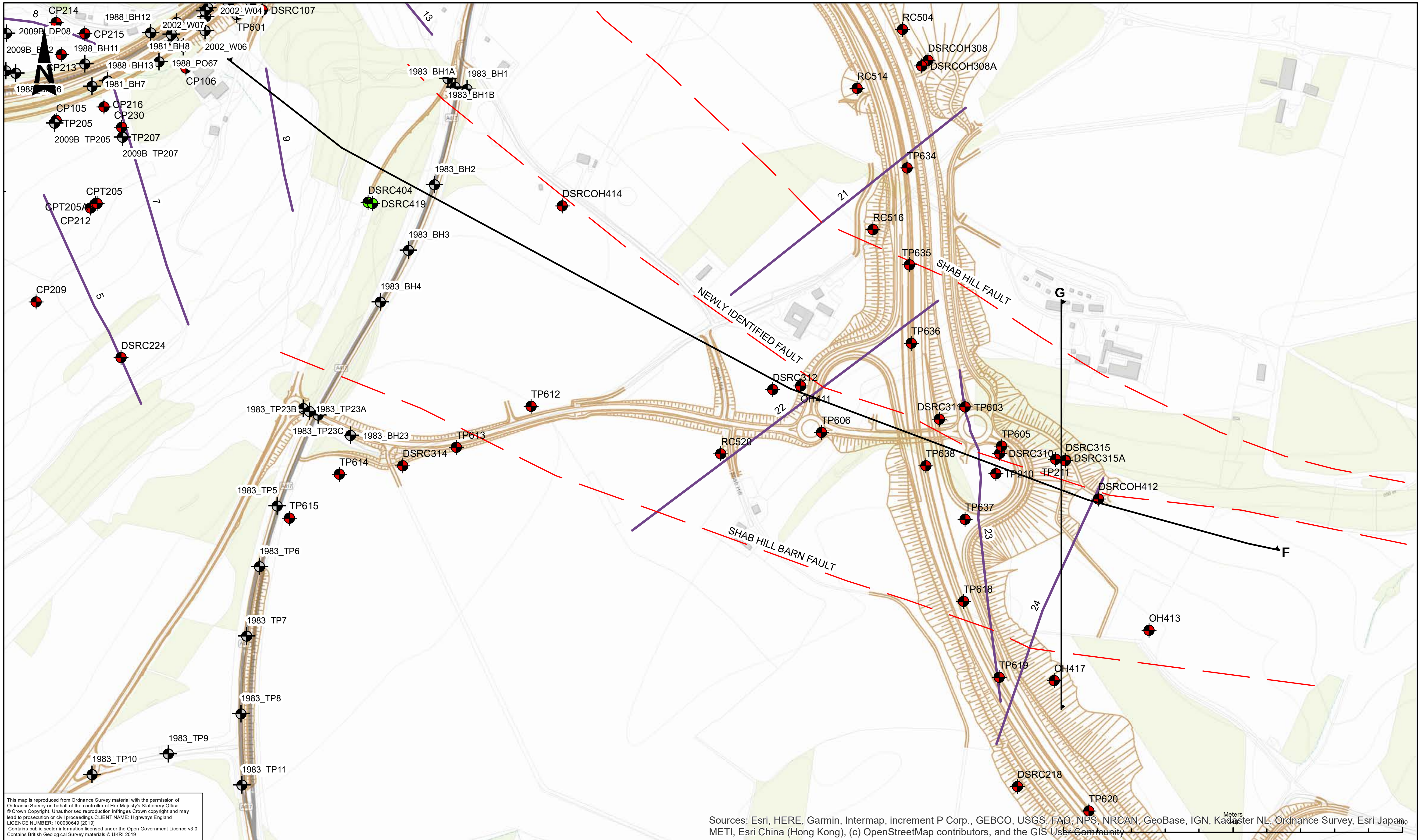


LEGEND

Investigat

- Phase 1
- Phase 2A
- REVISED FAULT LINES
- Surface Geophysics Section Lines
- Conceptual section lines

A417 Missing Link
Conceptual Section Map A - E
09/03/2021



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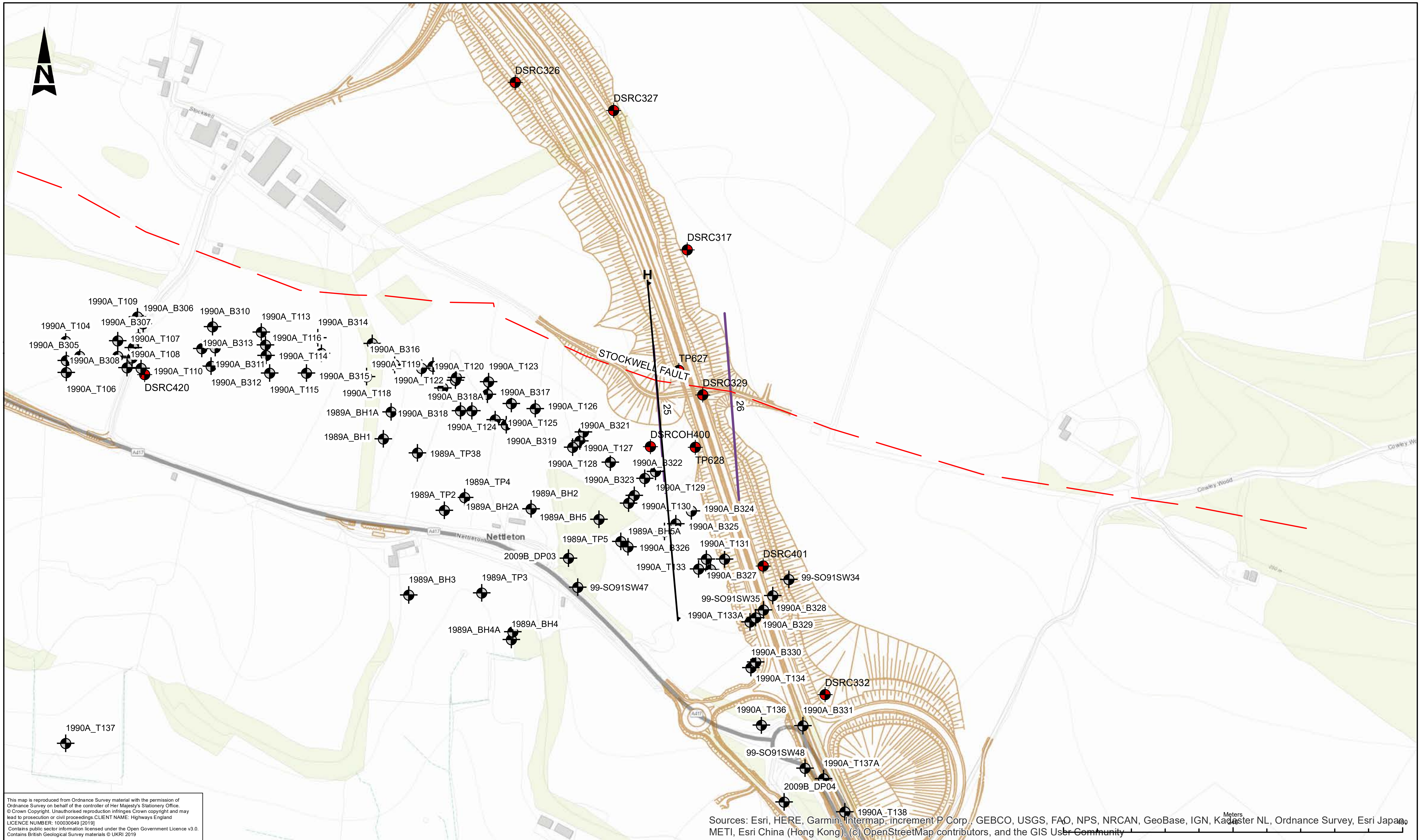
LEGEND

Investigat

- Phase 1
- Phase 2A
- HISTORIC EXPLORATORY HOLES
- REVISED FAULT LINES
- Surface Geophysics Section Lines
- Conceptual section lines

A417 Missing Link
Conceptual Section Map F & G
09/03/2021



LEGEND

Investigat

- Phase 1
- Phase 2A
- HISTORIC EXPLORATORY HOLES
- REVISED FAULT LINES
- Surface Geophysics Section Lines
- Conceptual section lines

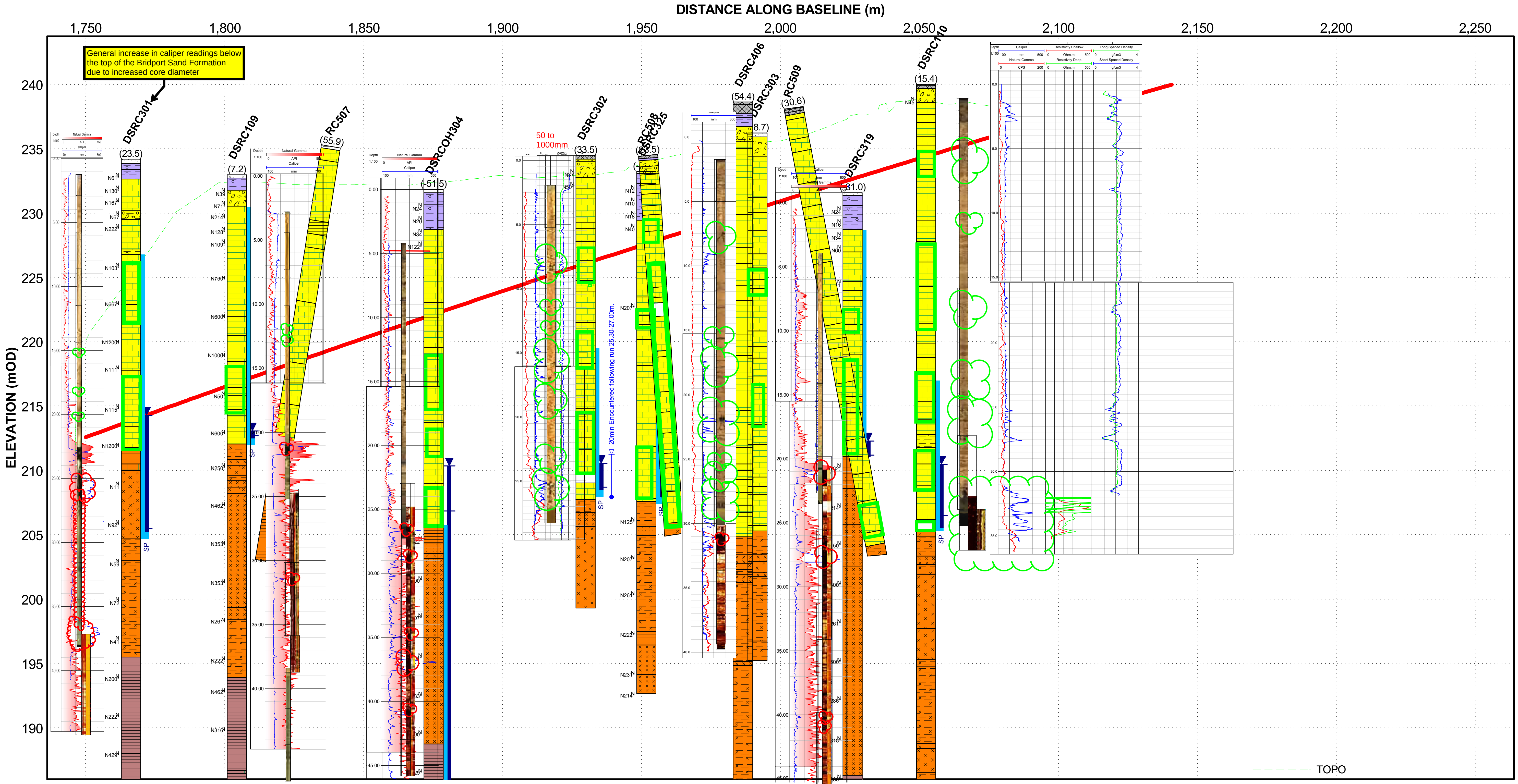
A417 Missing Link
Conceptual Section Map H
09/03/2021

Conceptual section A

Conceptual Section B

Conceptual Section C

Conceptual Section D



LEGEND

Hole offset is +ve to the RIGHT of the baseline

HoleID

(Offset)

SPT N value, * denotes N extrapolated by gINT:
* from main blows
** from seating blows

N20*

Water strikes during boring / excavation

Time for reported water rise and flow rate remarks

20min. Steady flow

Level that water rose to

Level of water strike

Piezometer readings

Range of water levels (note that erroneous or misleading readings have been filtered out)

Piezo response zone

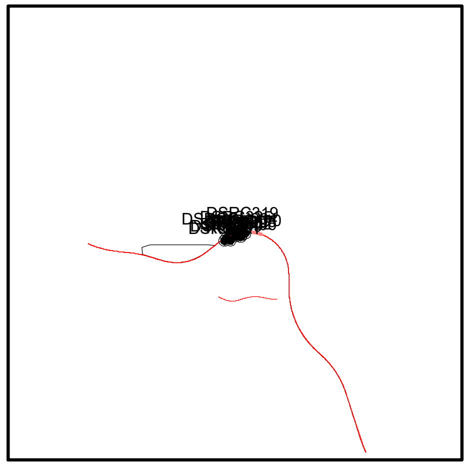
Tip depth

SPIE

Type of piezometer

Key to piezo types:
SP Standpipe

PLAN



COLOUR LEGEND

- Whitby Mudstone Formation [WHM]
- Birdlip Limestone Formation [BLPL]
- Bridport Sand Formation [BDS]
- Head Deposits [HDD]
- Made Ground [MG]
- Voids described on the core logs
- Voids identified with the downhole geophysics - Bridport Sand Formation
- Voids identified with the downhole geophysics - Inferior Oolite Group

MATERIALS

Gravelly SILT	Made Ground - FILL	SANDSTONE
Gravelly CLAY	Fill (MADE GROUND)	Clayey SAND
Sandy GRAVEL	Sandy CLAY	Gravelly SAND
LIMESTONE		
Silty Clay	SILT	
SILTSTONE	TOPSOIL	
Sandy SILT	Clayey GRAVEL	
MUDSTONE	CLAY	

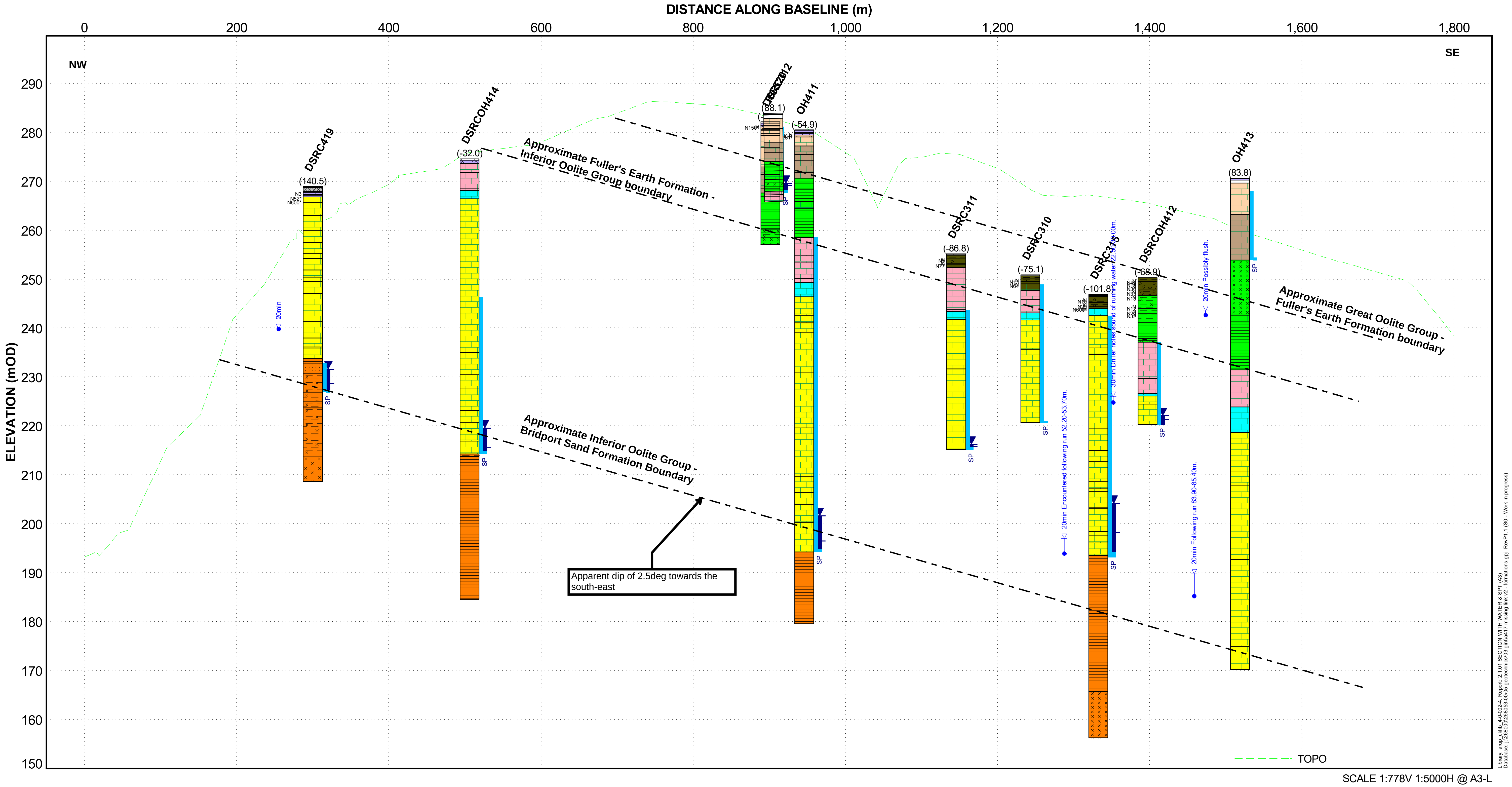
A417 - MISSING LINK GEOLOGICAL CROSS SECTION

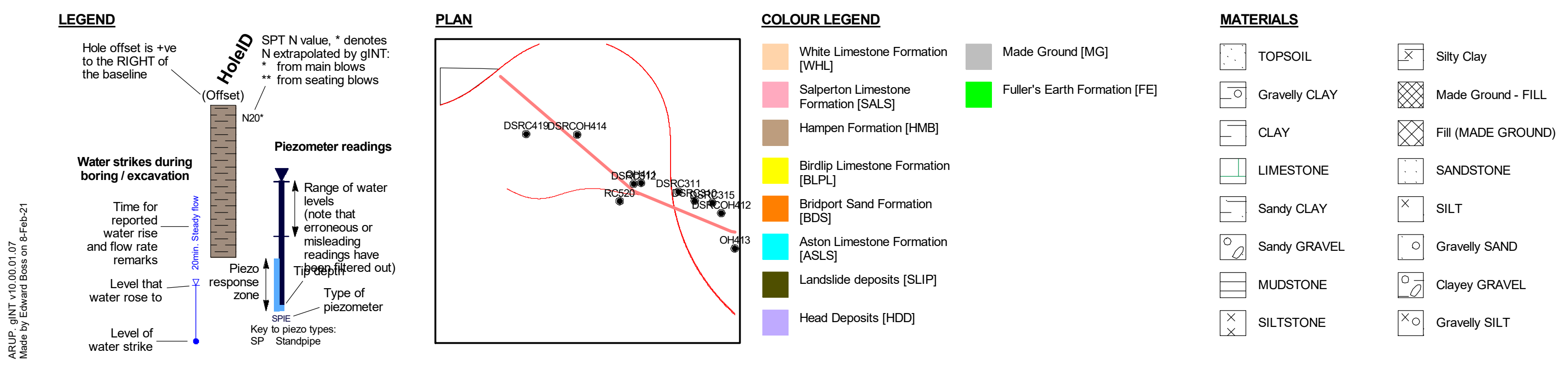
Conceptual Section E

268053-00

ARUP: gINT v10.00.01.07
Made by Edward Boss on 11-Feb-21

Library: arup_uklib_4-0-002-4. Report: 2.1.01 SECTION WITH WATER & SPT (A3) RevP1.1 (S0 - Work in progress)

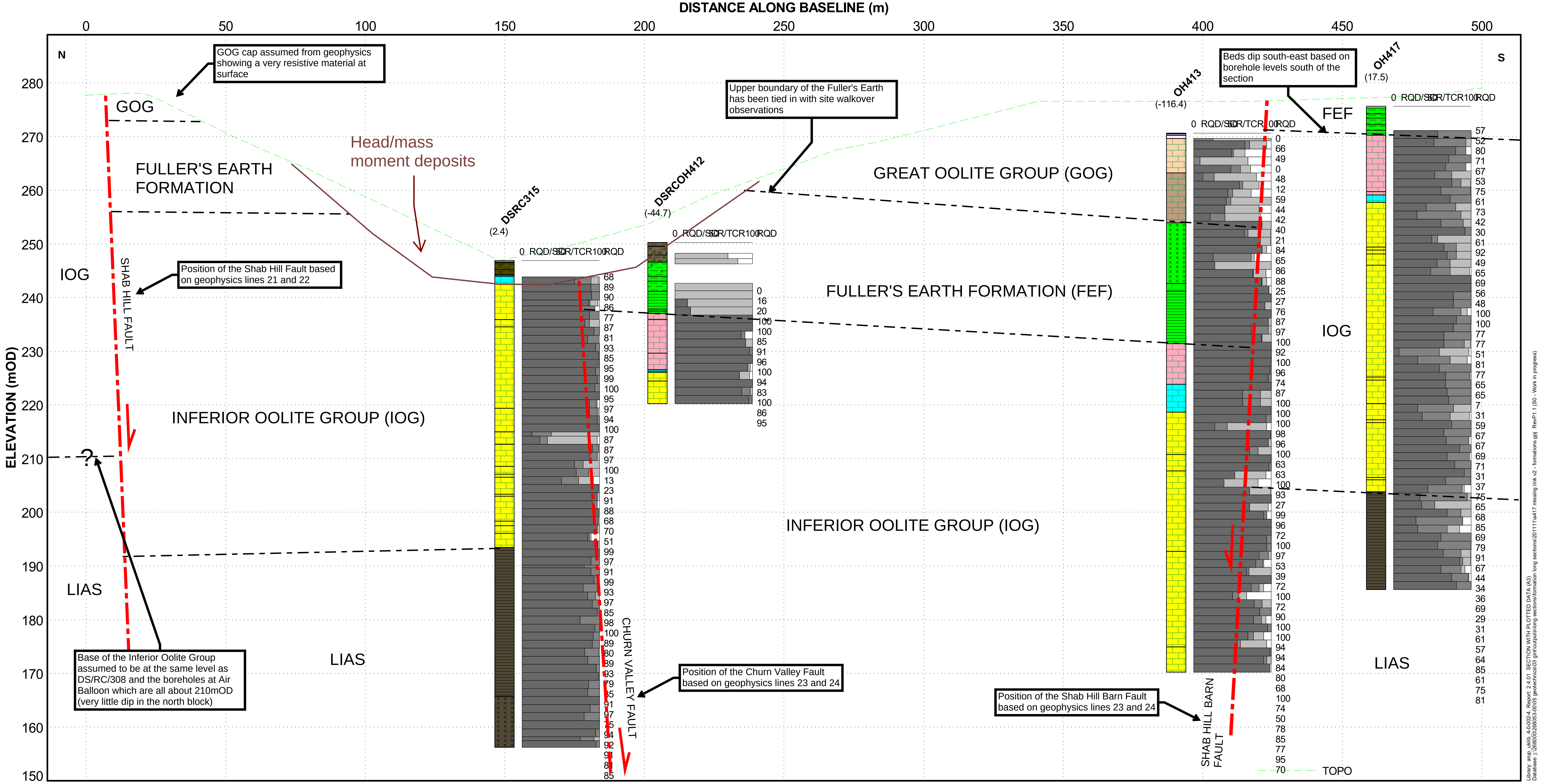




A417 - MISSING LINK
GEOLOGICAL CROSS SECTION

Conceptual Section F

268053-00

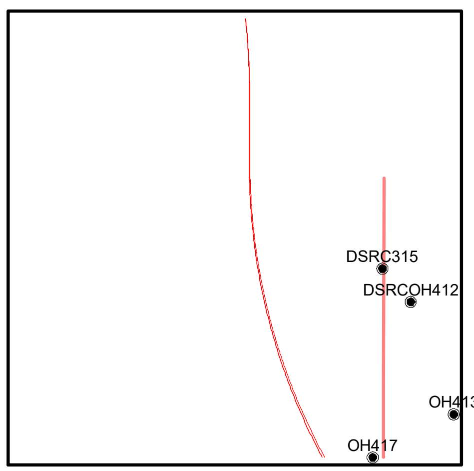


LEGEND

Hole offset is +ve to the RIGHT of the baseline

HoleID
(Offset)

PLAN



COLOUR LEGEND

- Landslide - Bridport sand material [SLIP_BDS]
- White Limestone Formation [WHL]
- Salperton Limestone Formation [SALS]
- Hampen Formation [HMB]
- Birdlip Limestone Formation [BLPL]
- Bridport Sand Formation [BDS]
- Aston Limestone Formation [ASLS]
- Landslide deposits [SLIP]
- Head Deposits [HDD]
- Fuller's Earth Formation [FE]

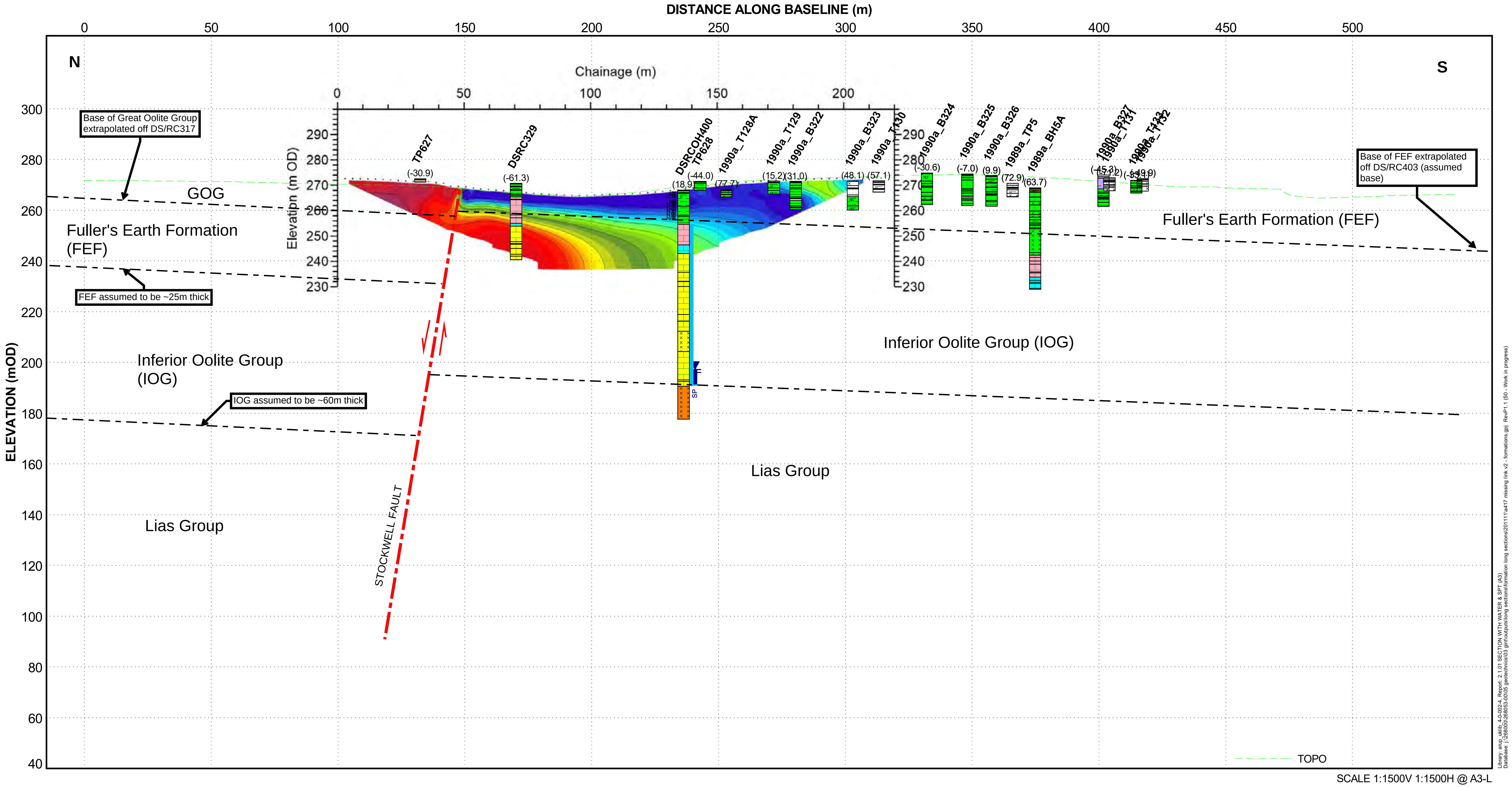
MATERIALS

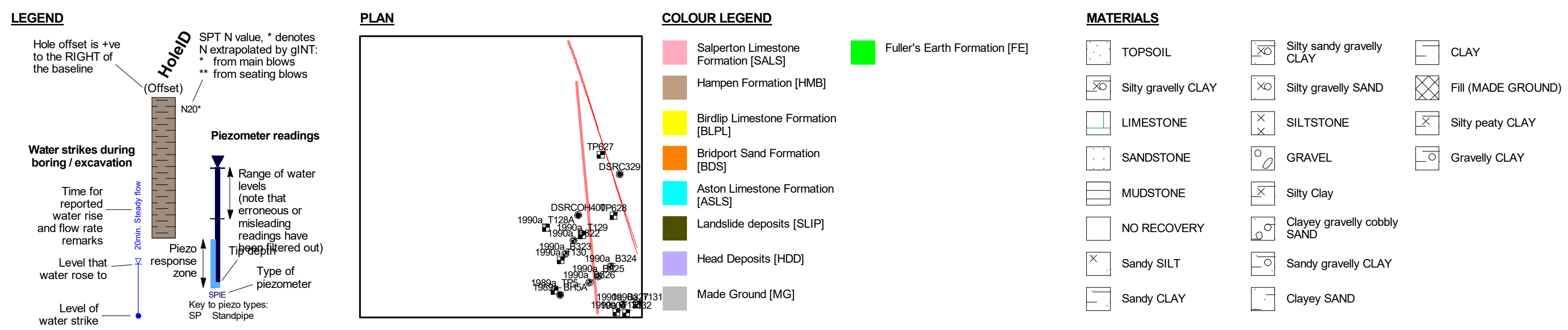
- TOPSOIL
- Gravelly CLAY
- Sandy CLAY
- LIMESTONE
- MUDSTONE
- SILTSTONE
- CLAY
- Gravelly SAND
- Sandy GRAVEL
- Clayey GRAVEL
- Silty Clay

A417 - MISSING LINK
GEOLOGICAL CROSS SECTION

Conceptual Section G

268053-00





ARUP: gINT v10.00.01.07
Made by Edward Boss on 24-Feb-21

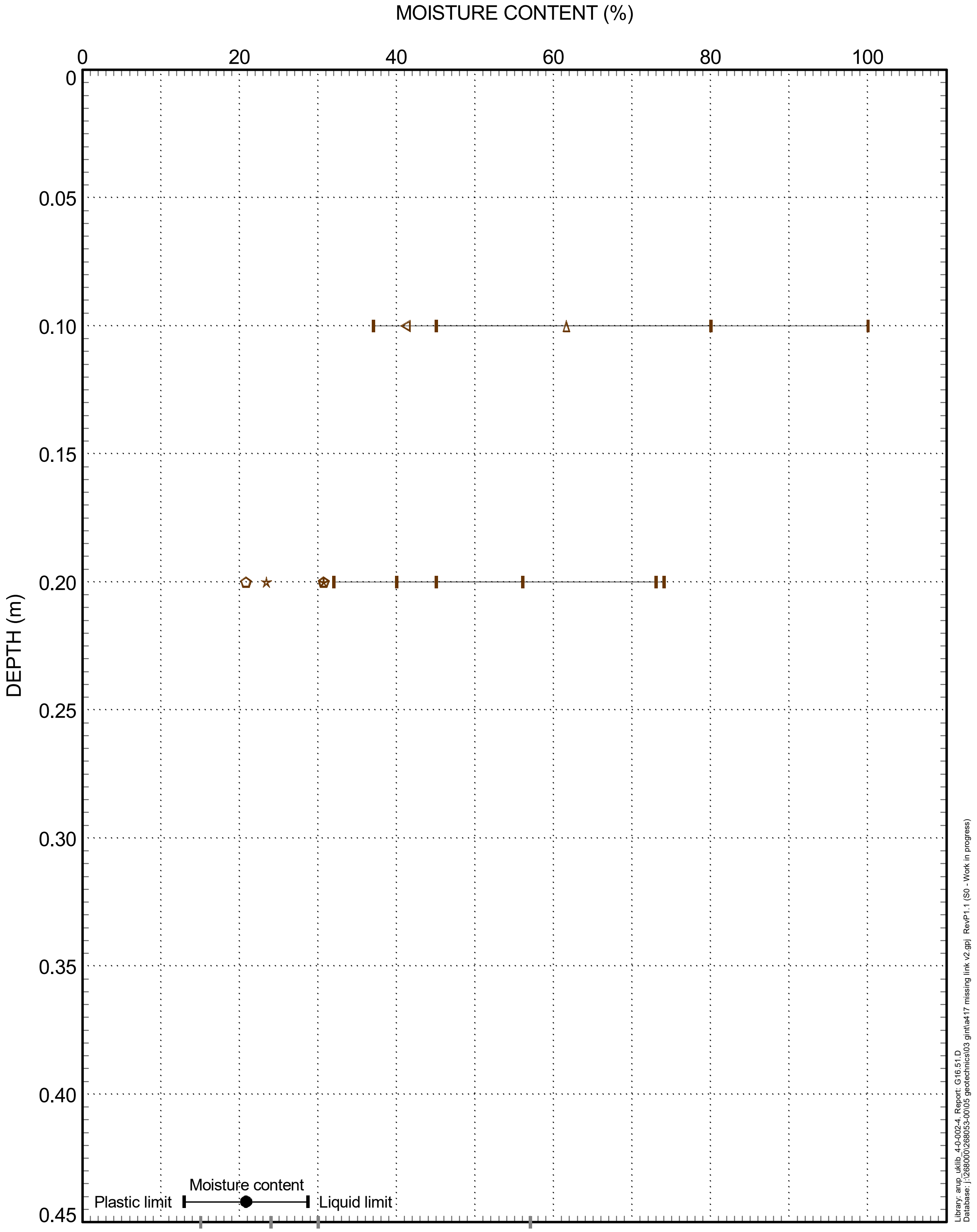
A417 - MISSING LINK
GEOLOGICAL CROSS SECTION

Conceptual Section H

268053-00

Appendix F Parameter plots

F.1 Topsoil

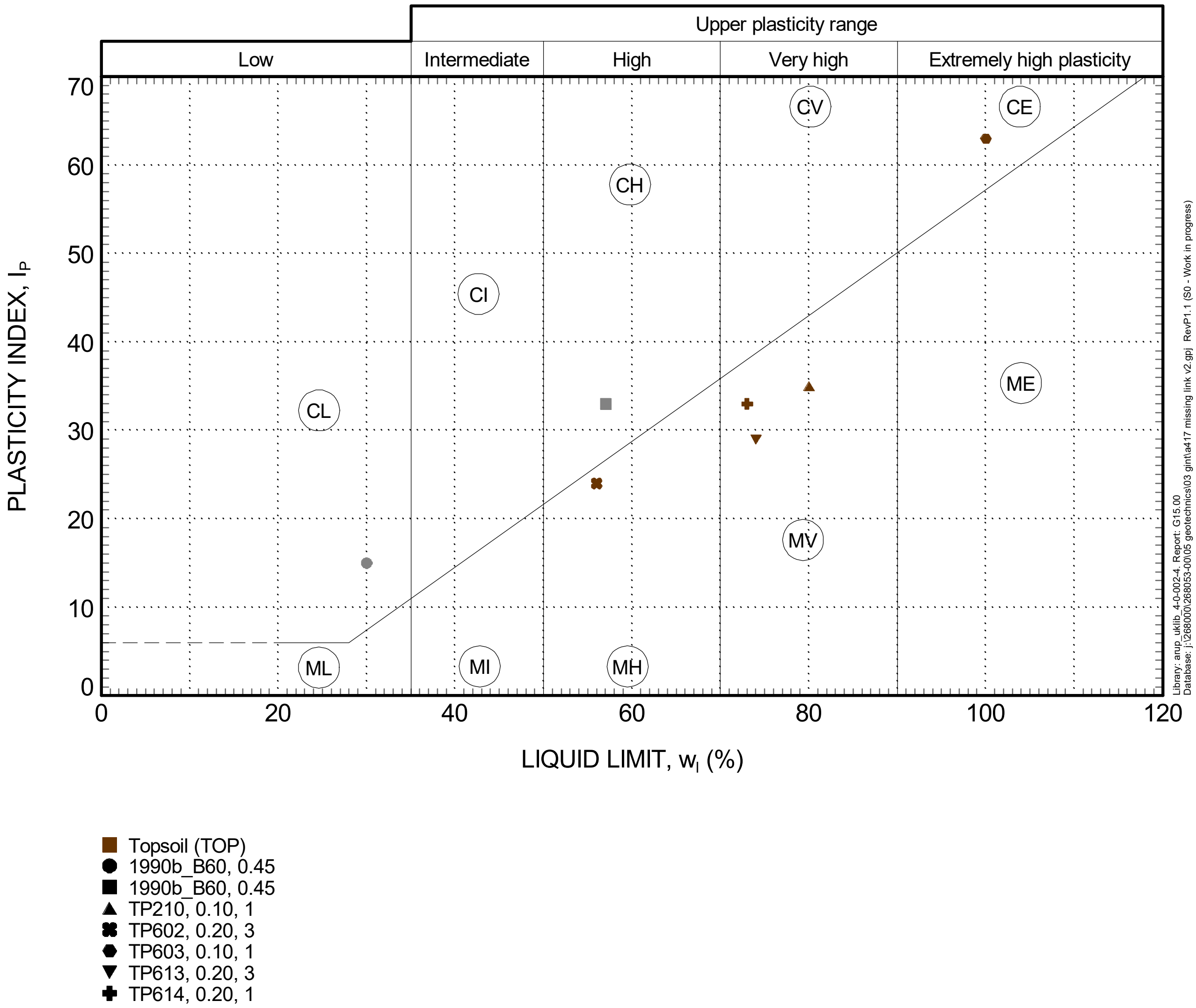


Topsoil (TOP)
1990b_B60
TP210
TP602
TP603
TP613
TP614

A417 - MISSING LINK
ATTERBERG LIMITS
TOPSOIL

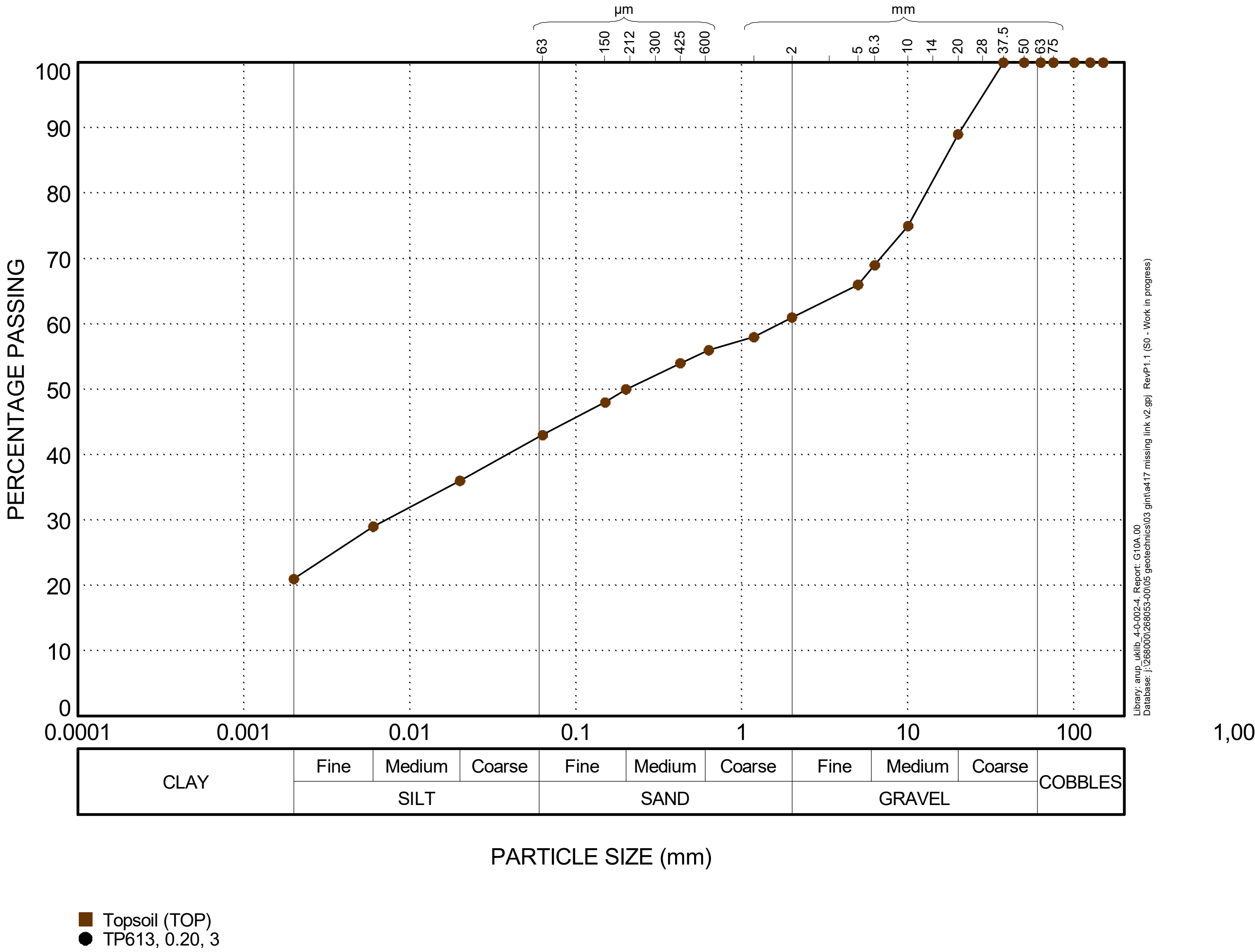
FIGURE: F1.01

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



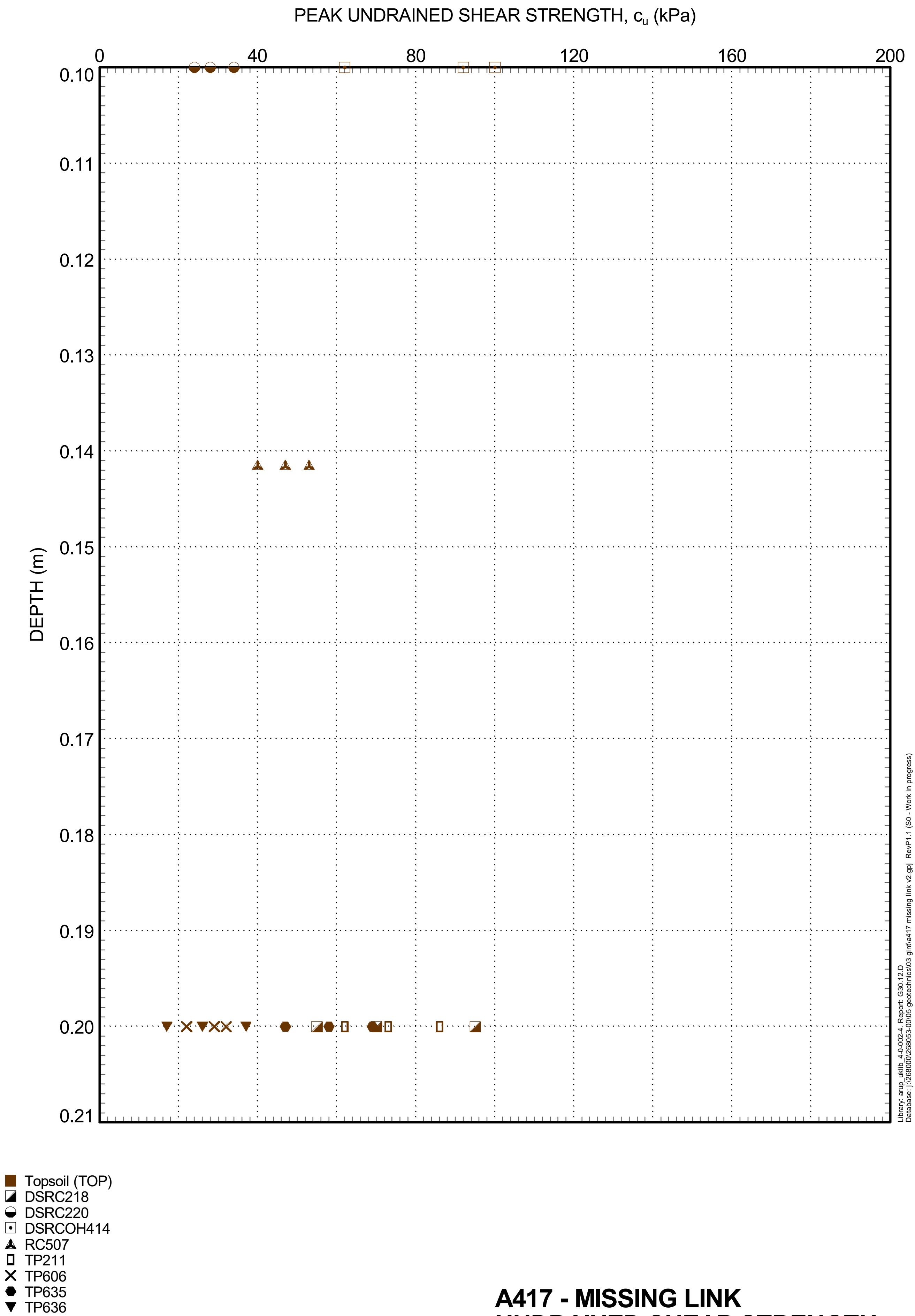
A417 - MISSING LINK
PLASTICITY CHART
TOPSOIL

FIGURE: F1.02



A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
TOPSOIL

FIGURE: F1.03



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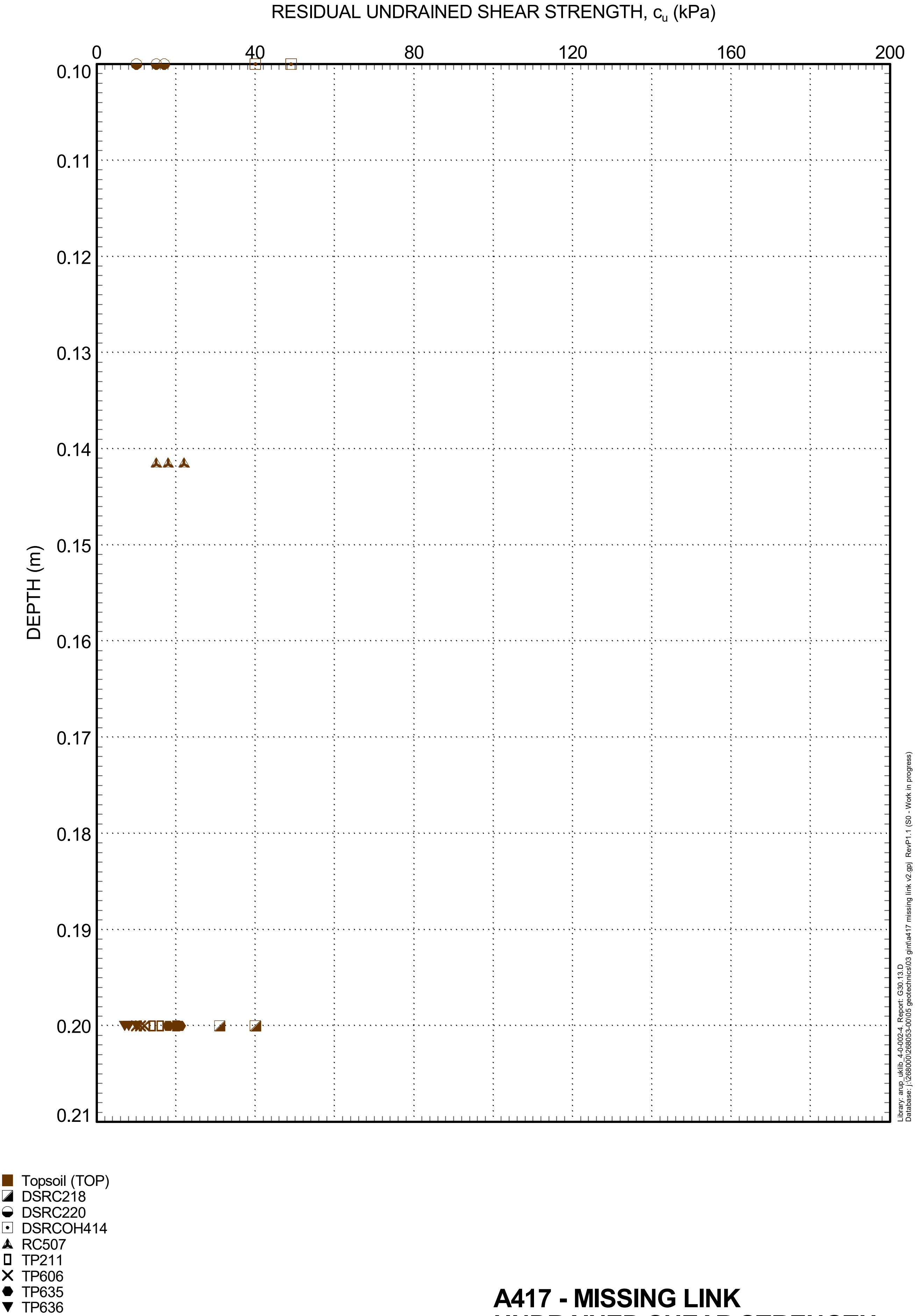
ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM HAND VANE
TOPSOIL

FIGURE: F1.04

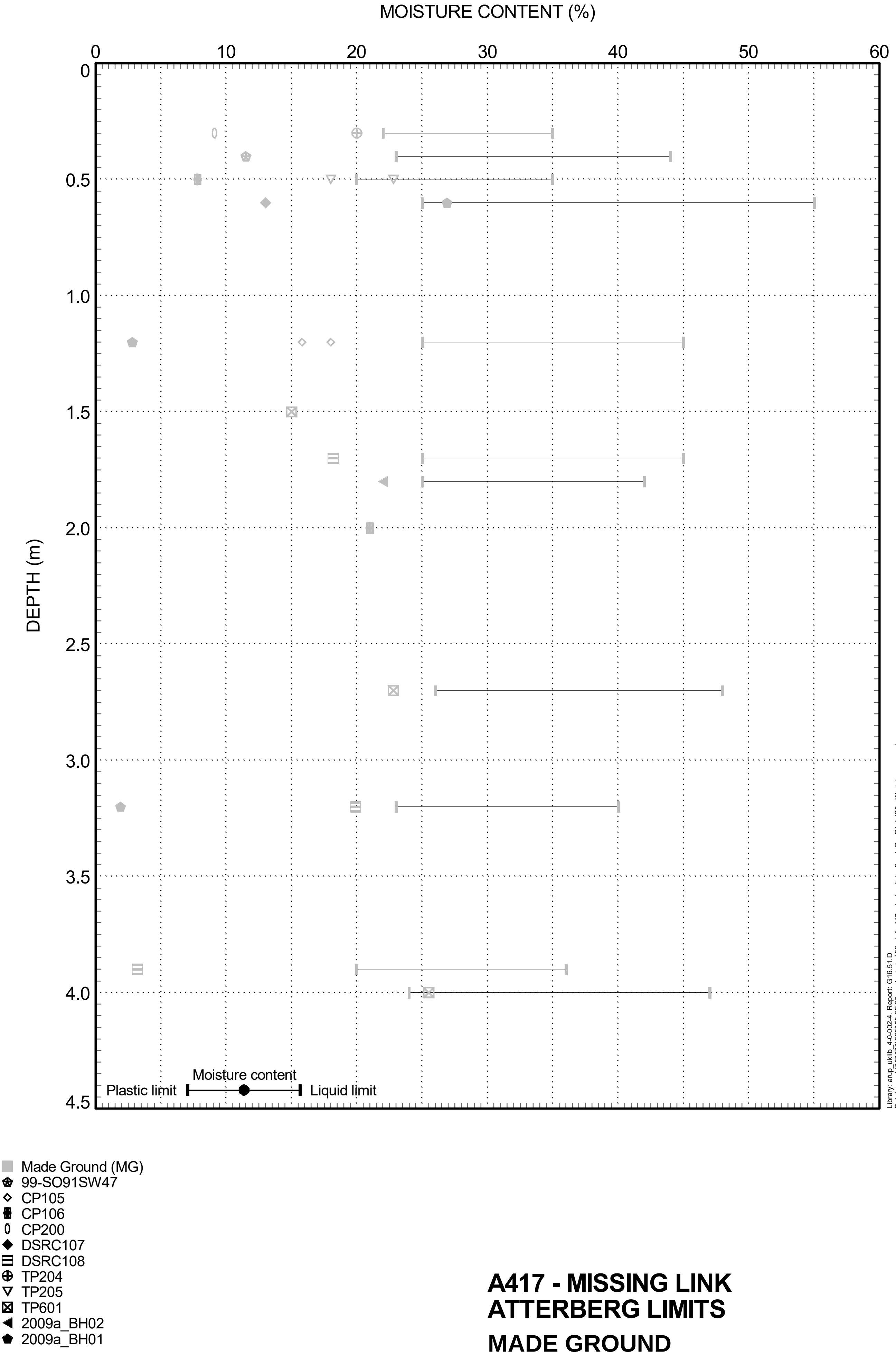


A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM HAND VANE

TOPSOIL

FIGURE: F1.05

F.2 Made Ground



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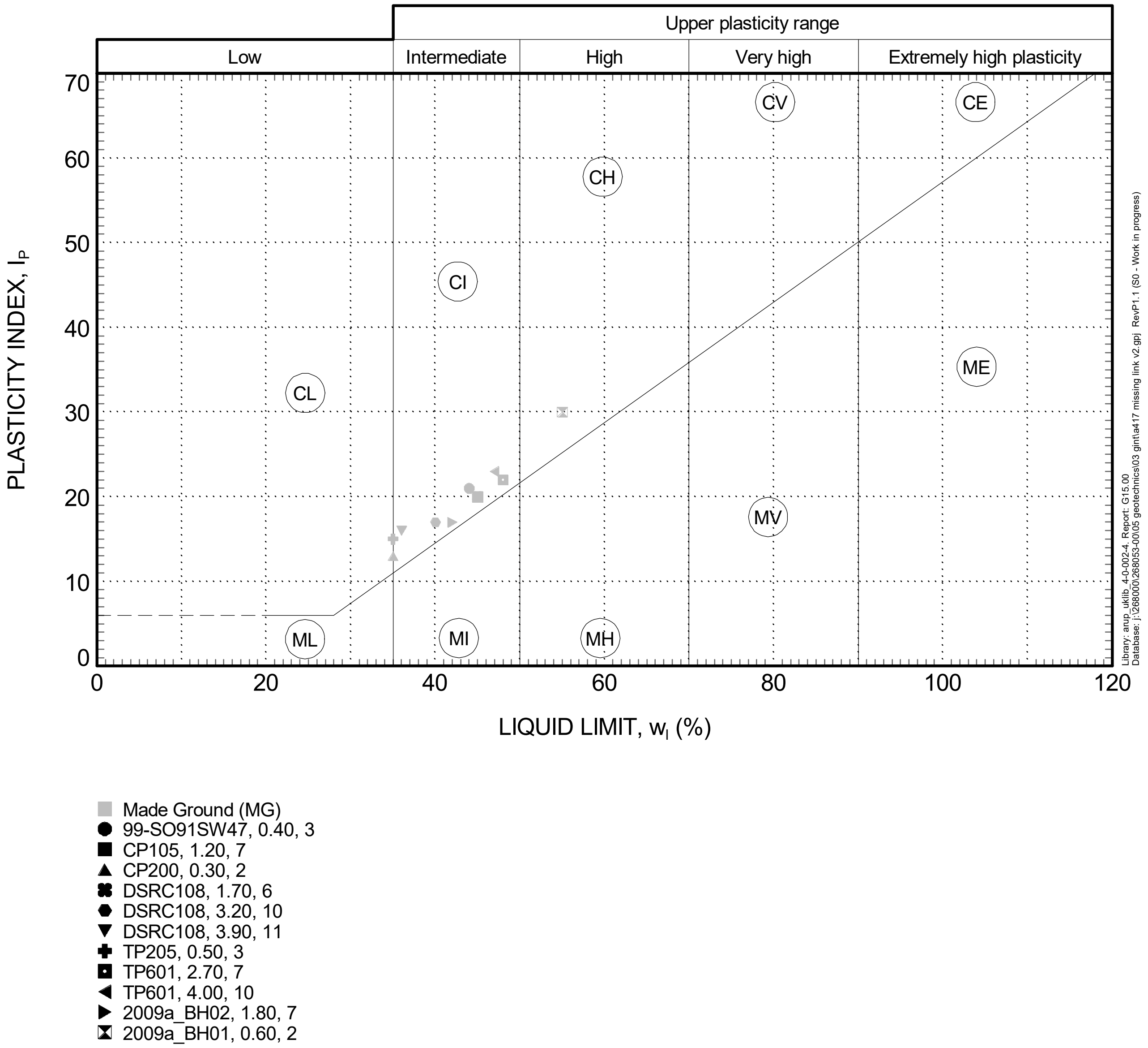
ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ATTERBERG LIMITS

MADE GROUND

FIGURE: F2.01



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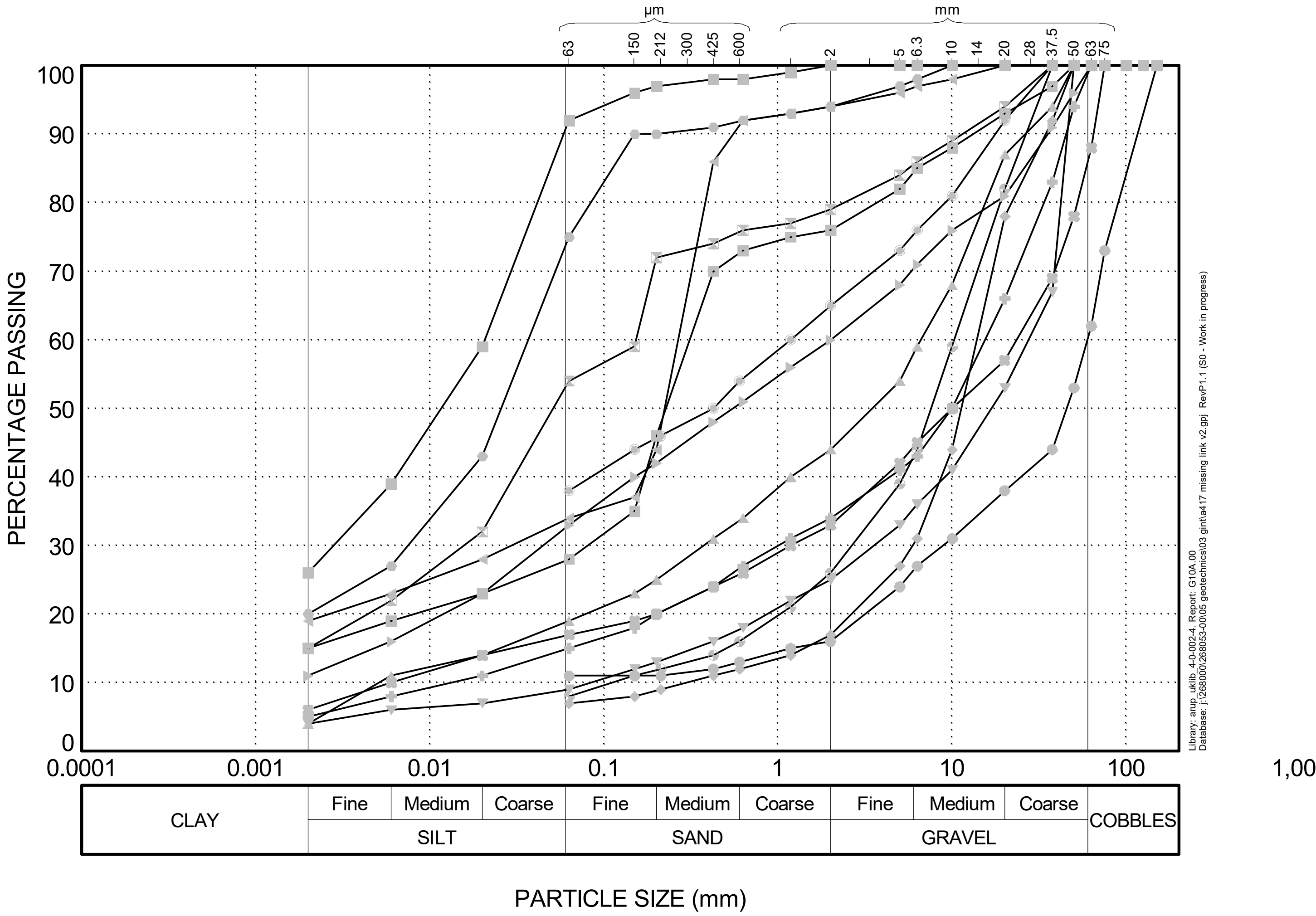
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
PLASTICITY CHART
MADE GROUND

FIGURE: F2.02

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

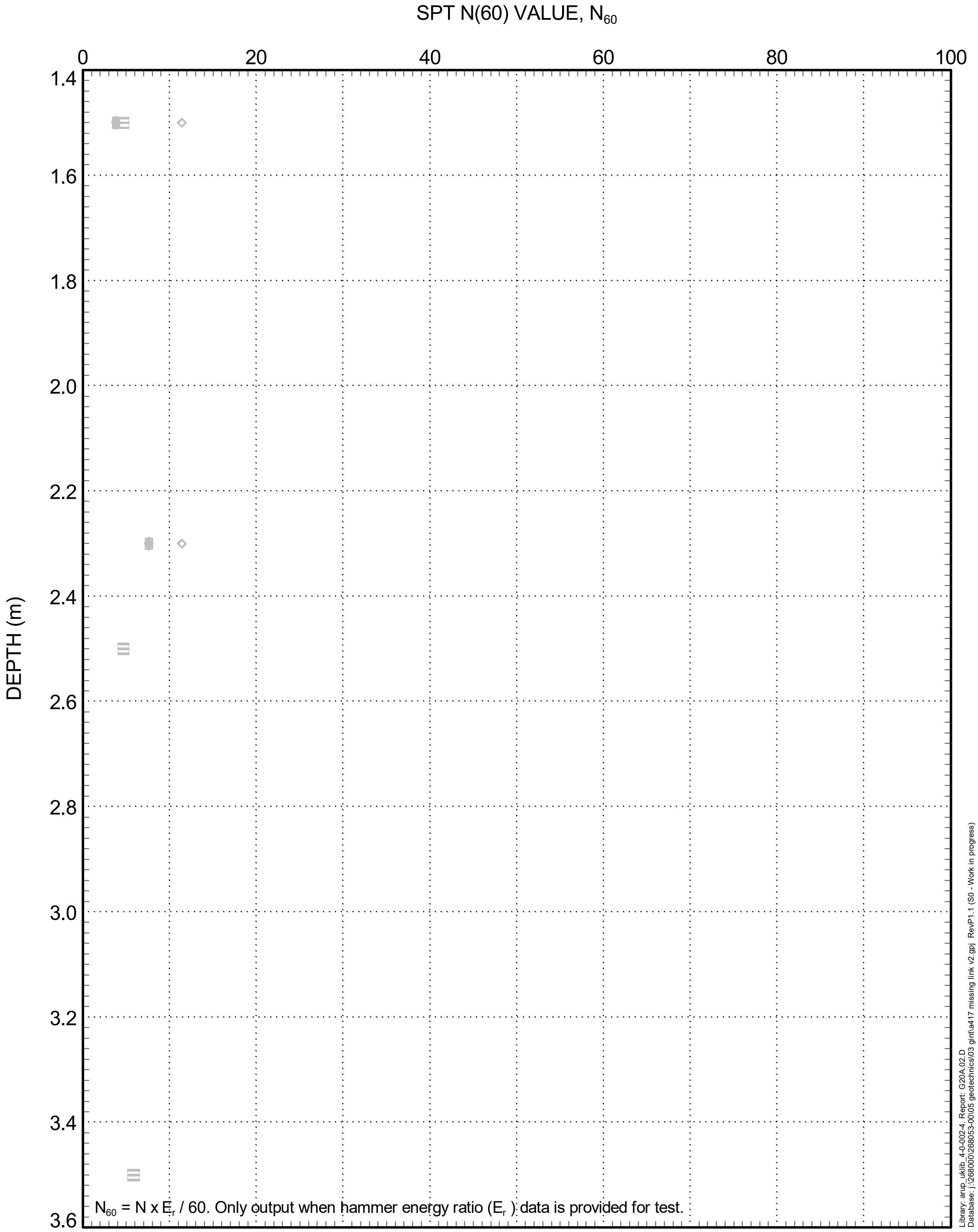


- Made Ground (MG)
- 99-SO91NW156, 0.50, 3
- CP105, 1.20, 8
- CP106, 1.00, 3
- DSRC108, 1.00, 3
- DSRC108, 3.90, 11
- DSRC110, 0.06, 2
- RC509, 0.50, 5
- TP601, 0.50, 2
- TP601, 1.50, 5
- TP601, 2.70, 8
- TP601, 4.30, 11
- 2009a_BH02, 3.00, 9
- 2009a_BH01, 1.20, 5
- 2009a_BH01, 3.20, 8

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
MADE GROUND

FIGURE: F2.03



Made Ground (MG)
CP105
CP106
DSRC108

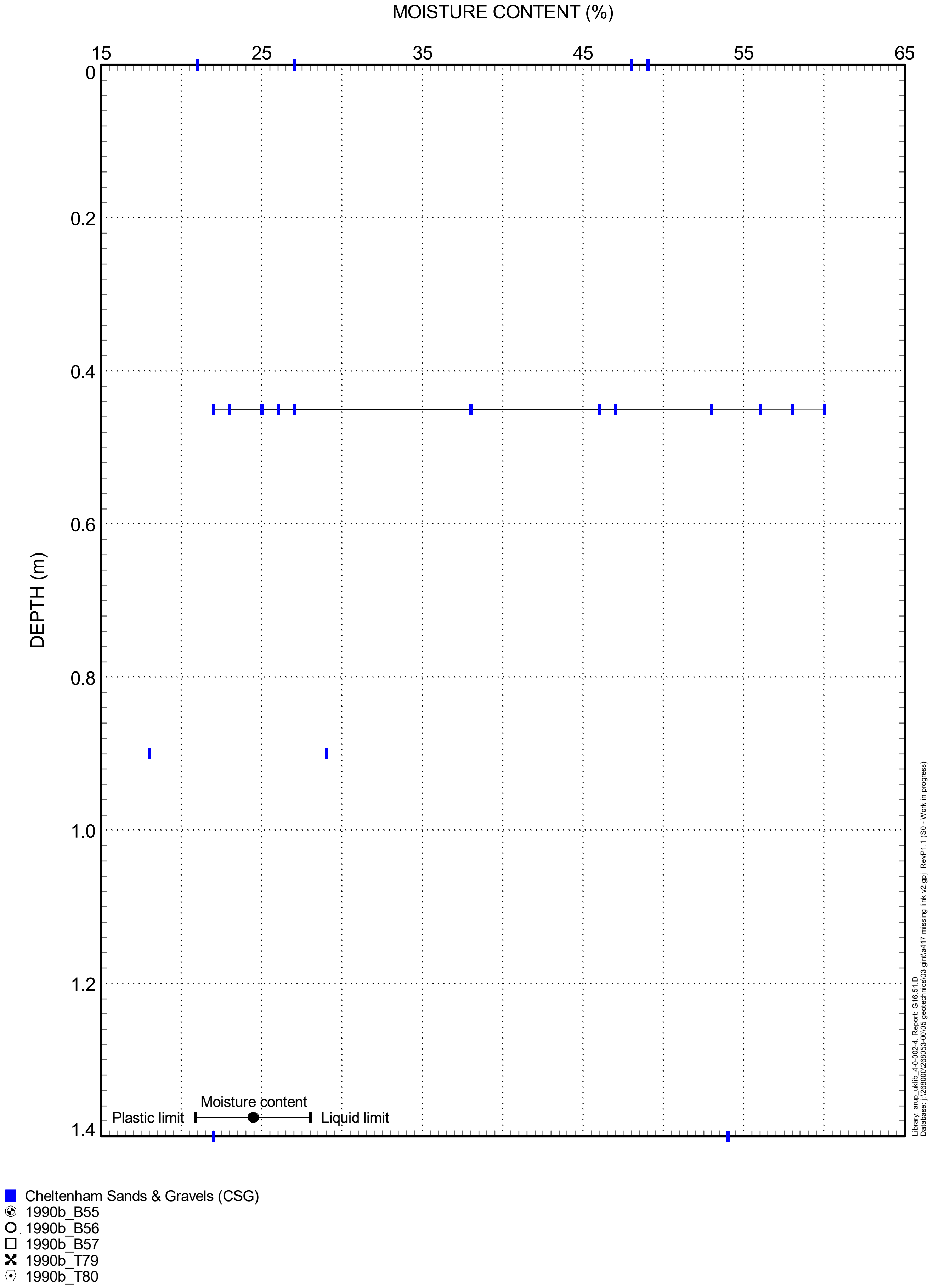
ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
STANDARD PENETRATION TESTS

MADE GROUND

FIGURE: F2.04

F.3 Cheltenham Sands and Gravels



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Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
ATTERBERG LIMITS
CHELTENHAM SANDS & GRAVELS

FIGURE: F3.01

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

Frank Graham
Consulting Engineers

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SOUTH WEST REGION
DIRECTOR (CONSTRUCTION PROGRAMME)
W.E. GALLAGHER B.Sc.(ENG) C.ENG. M.I.C.E

A417 BROCKWORTH BYPASS
GEOTECHNICAL INTERPRETATIVE REPORT

FAN GRAVEL : MOISTURE CONTENT v DEPTH

Job No	CWH / 091073 / 024
Scale	NTS
Date	APRIL 91
Drawn	
Checked	
Fig. No.	7a

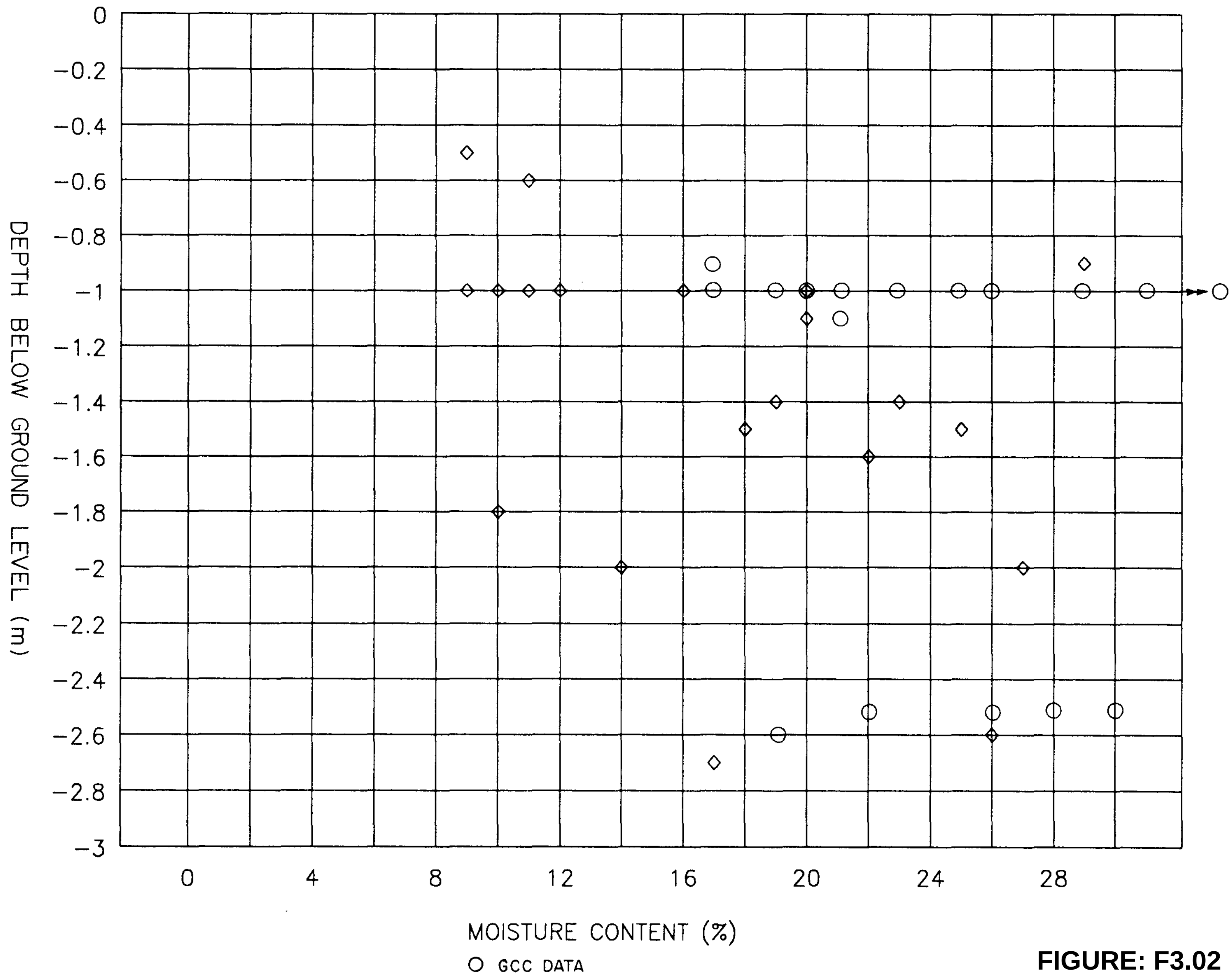
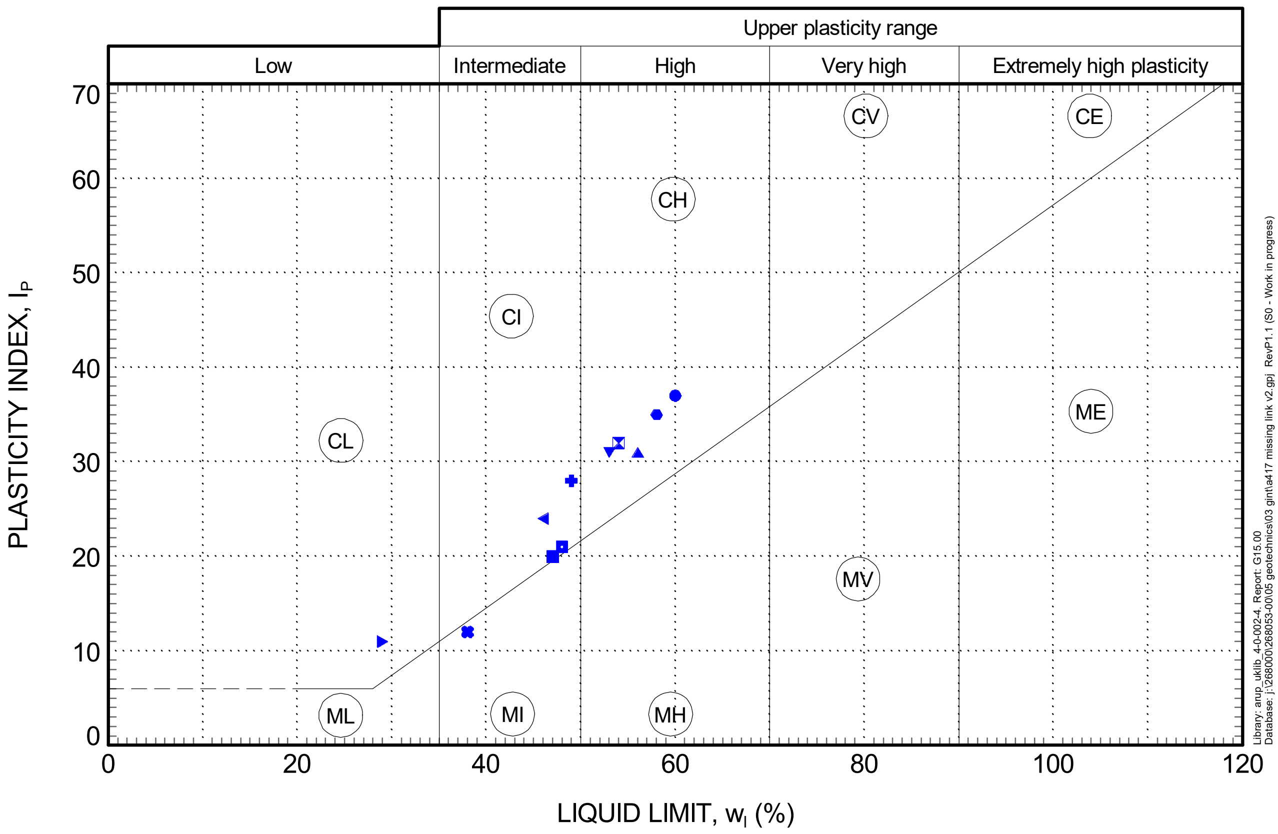


FIGURE: F3.02



■ Cheltenham Sands & Gravels (CSG)
● 1990b_B55, 0.45
■ 1990b_B55, 0.45
▲ 1990b_B55, 0.45
✖ 1990b_B56, 0.45
⬢ 1990b_B56, 0.45
▼ 1990b_B56, 0.45
✚ 1990b_B56, 0.00
▣ 1990b_B56, 0.00
◀ 1990b_B57, 0.45
▶ 1990b_T79, 0.90
⧗ 1990b_T80, 1.40

Library: arup_uklib_4-0-002-4. Report: G15.00
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
PLASTICITY CHART
CHELTENHAM SANDS & GRAVELS

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

FIGURE: F3.03

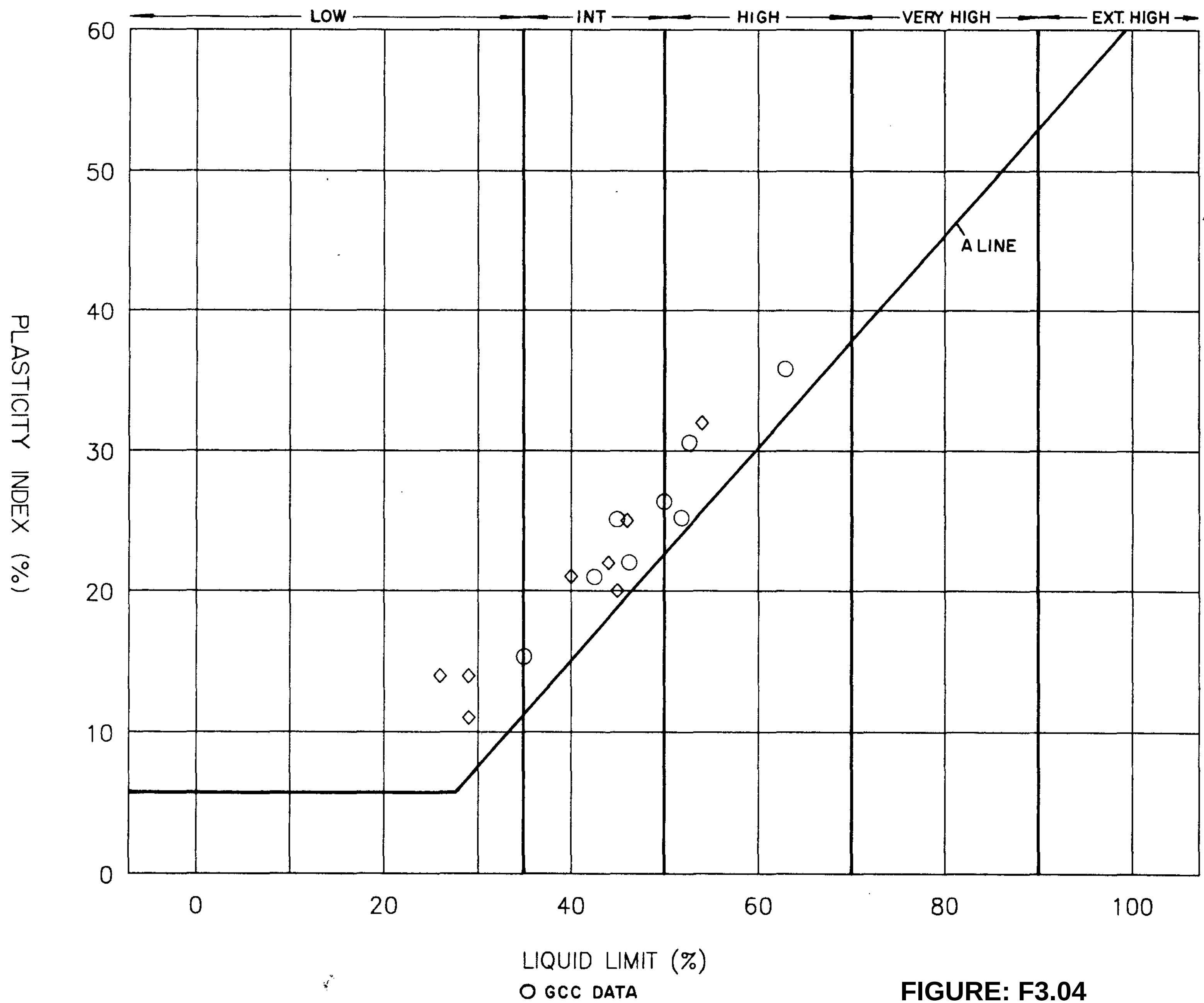


FIGURE: F3.04

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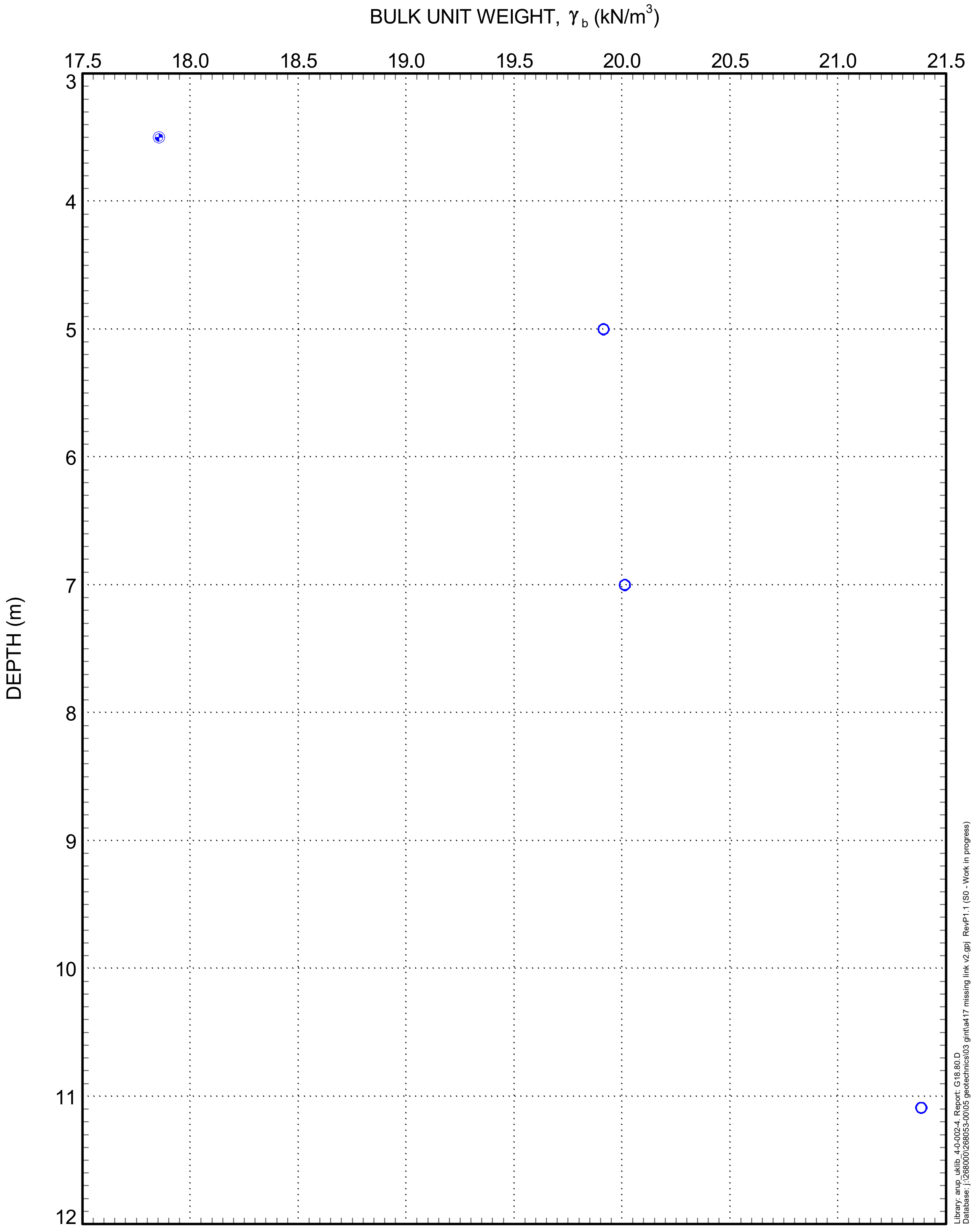
A417 BROCKWORTH BYPASS
GEOTECHNICAL INTERPRETATIVE REPORT

FAN GRAVEL : CASAGRANDE PLOT

Job No	CWH / 091073 / 024
Scale	NTS
Date	APRIL 91
Drawn	
Checked	
Fig. No.	7b



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Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

■ Cheltenham Sands & Gravels (CSG)
1990b_B55
1990b_B56

A417 - MISSING LINK
BULK UNIT WEIGHT
CHELTENHAM SANDS & GRAVELS

FIGURE: F3.05

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

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SOUTH WEST REGION
DIRECTOR (CONSTRUCTION PROGRAMME)
W E GALLAGHER B Sc (ENG) C ENG M I C E

A417 BROCKWORTH BYPASS
GEOTECHNICAL INTERPRETATIVE REPORT

FAN GRAVEL : BULK DENSITY v DEPTH

Job No	CWH / 091073 / 024
Scale	NTS
Date	APRIL 91
Drawn	
Checked	
Fig. No	7e

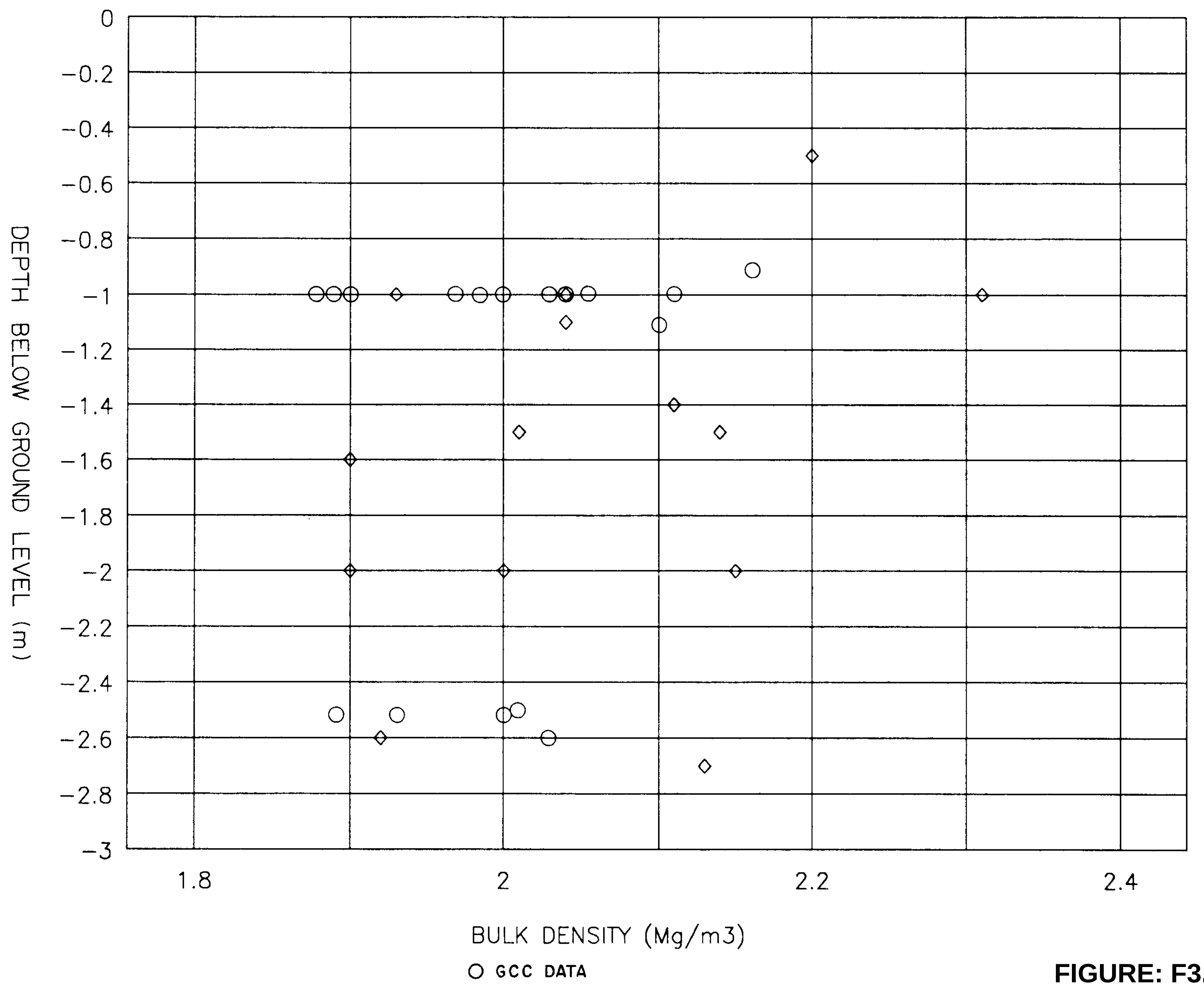

FIGURE: F3.06

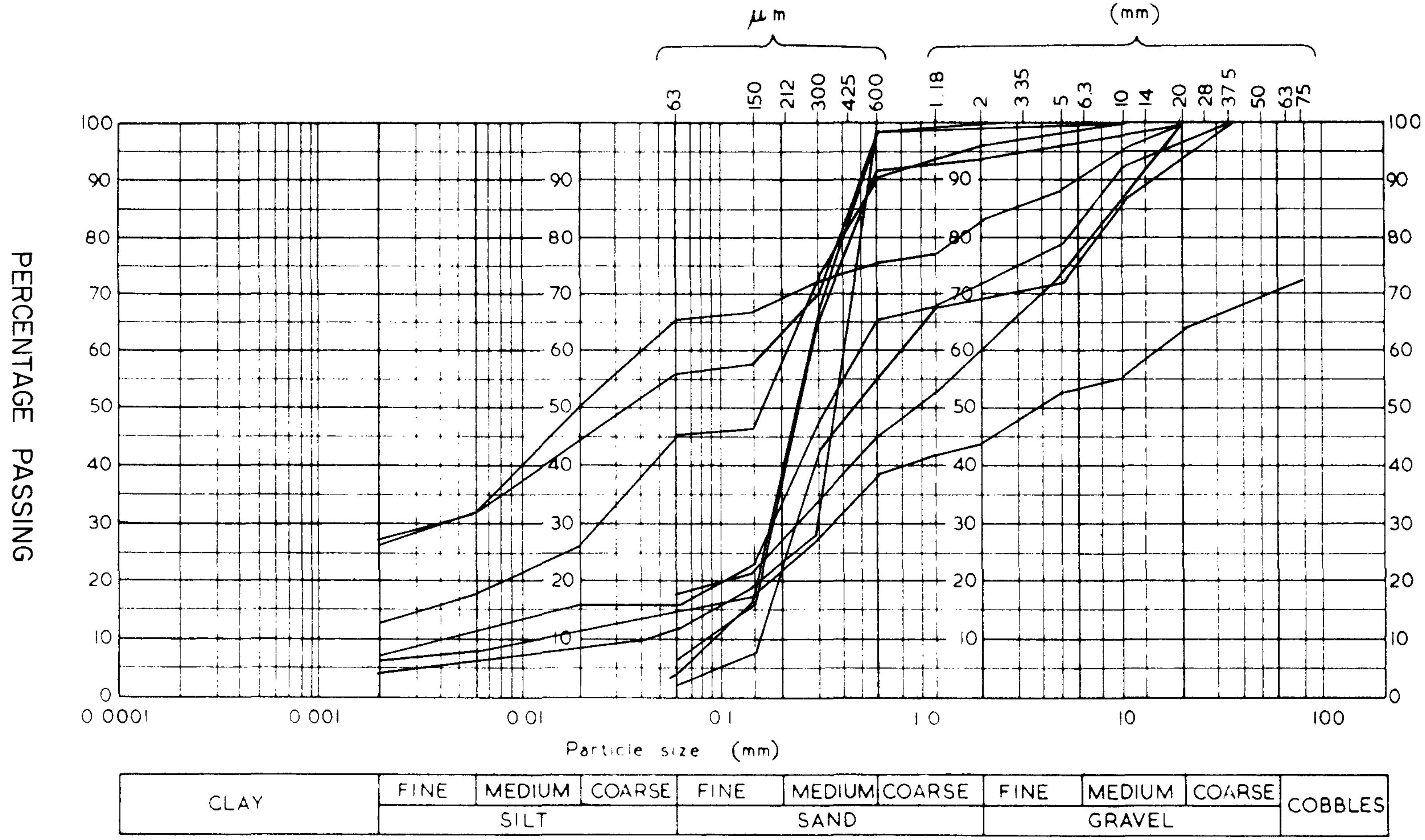

FIGURE: F3.07

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A417 BROCKWORTH BYPASS
GEOTECHNICAL INTERPRETATIVE REPORT

FAN GRAVEL : PARTICLE SIZE DISTRIBUTION

Job No	CWH / 091073 / 024
Scale	NTS
Date	APRIL 91
Drawn	
Checked	
Fig. No.	7d

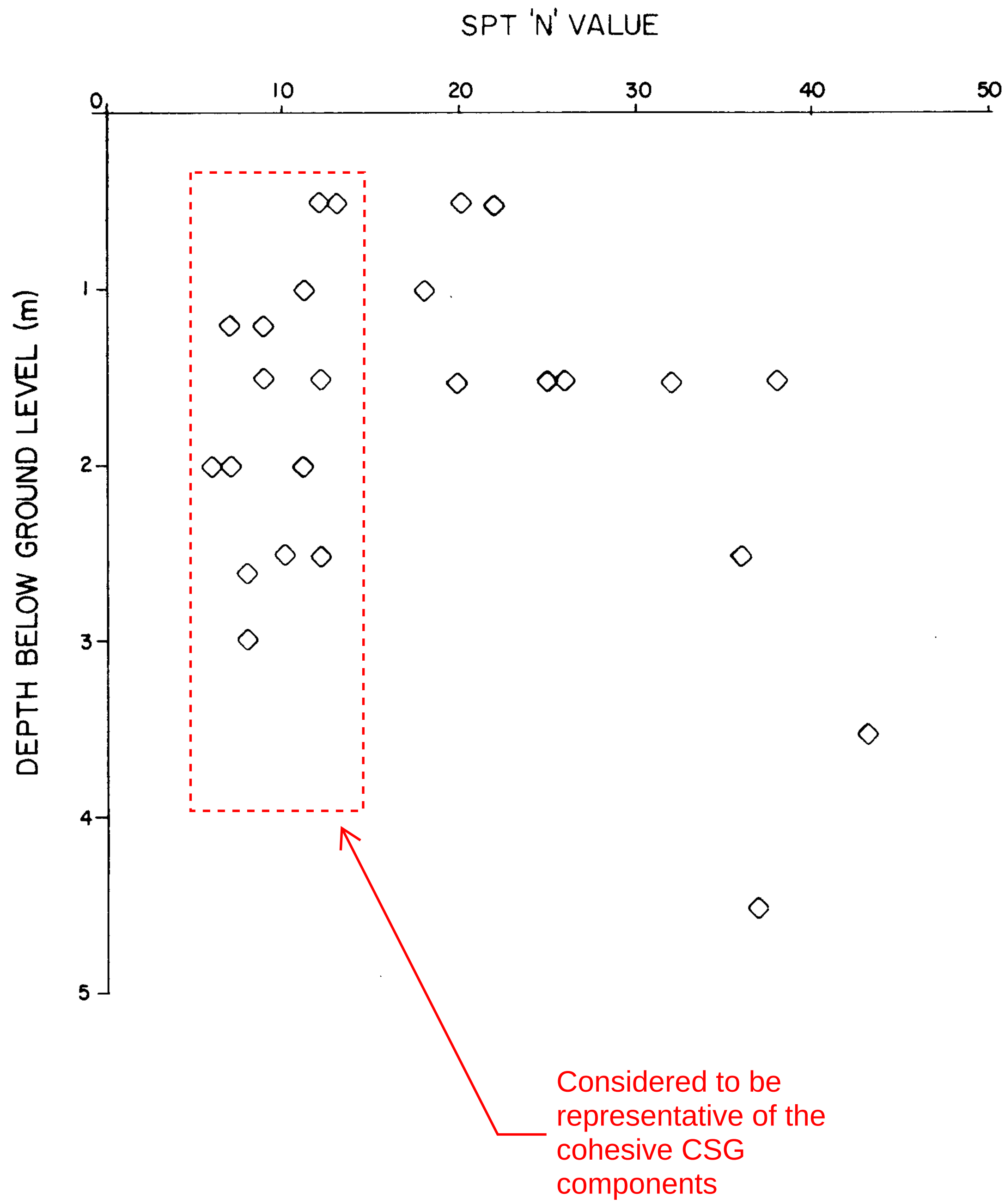
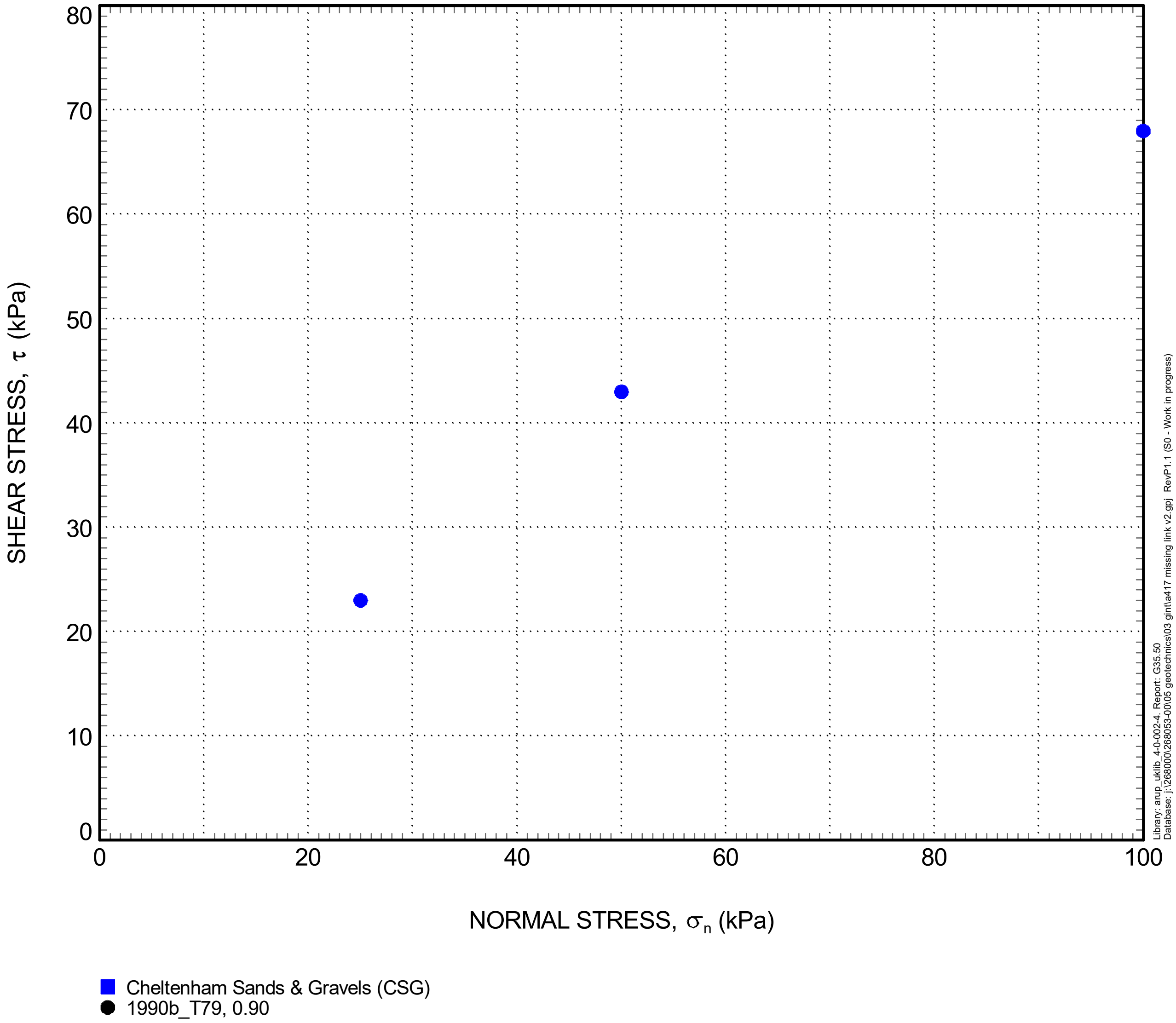


FIGURE: F3.08

FRANK GRAHAM Frank Graham Consulting Engineers	A417 BROCKWORTH BYPASS GEOTECHNICAL INTERPRETATIVE REPORT FAN GRAVEL : SPT v DEPTH				
THE DEPARTMENT OF TRANSPORT SOUTH WEST REGION DIRECTOR (CONSTRUCTION PROGRAMME) W.E. GALLAGHER B.Sc.(ENG) C.ENG. M.I.C.E.	Job No CWH / 091073 / 024				Fig. No. 7f
	Scale NTS	Date APRIL 91	Drawn	Checked	



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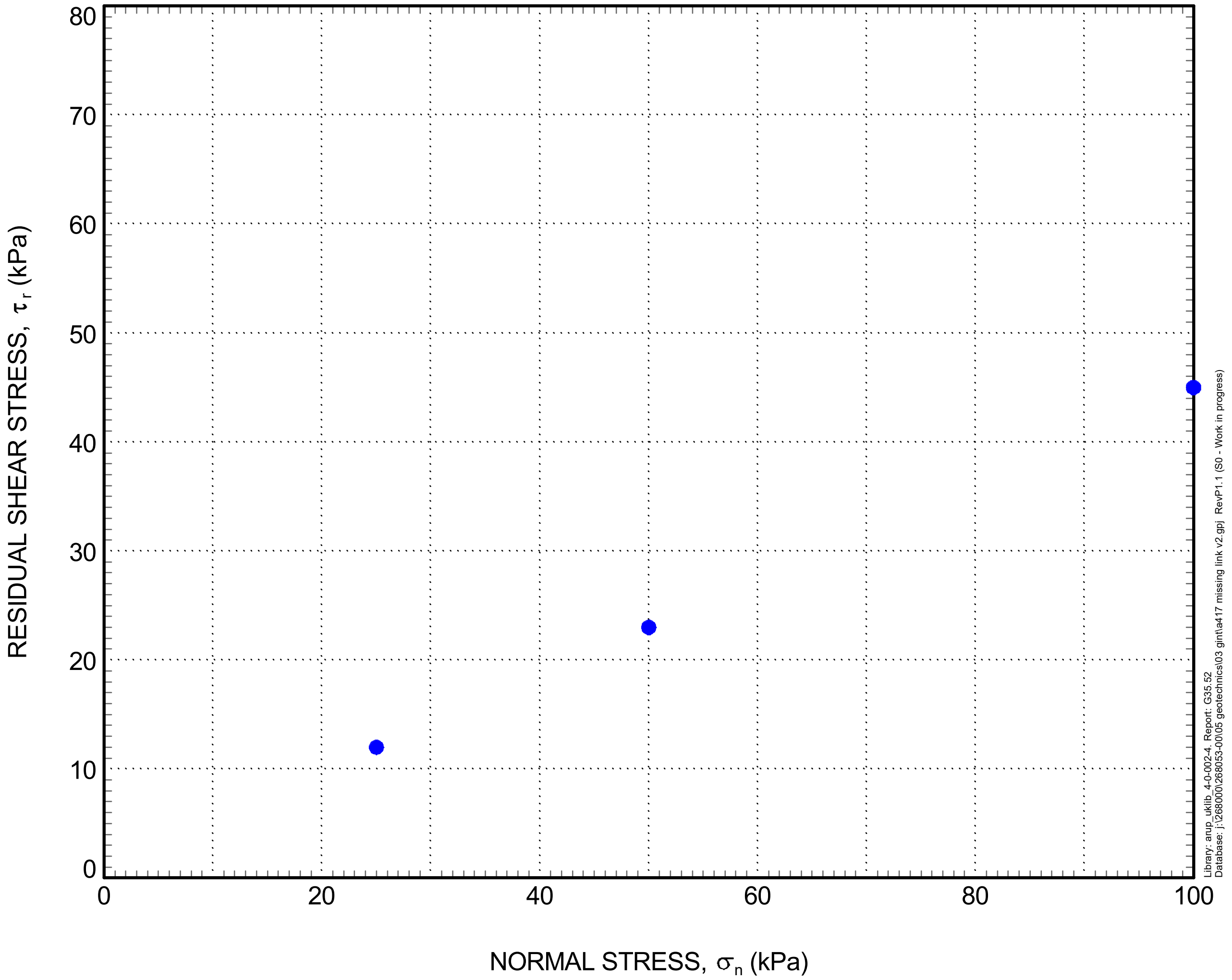
A417 - MISSING LINK
SHEAR BOX TESTS
CHELTENHAM SANDS & GRAVELS

FIGURE: F3.09

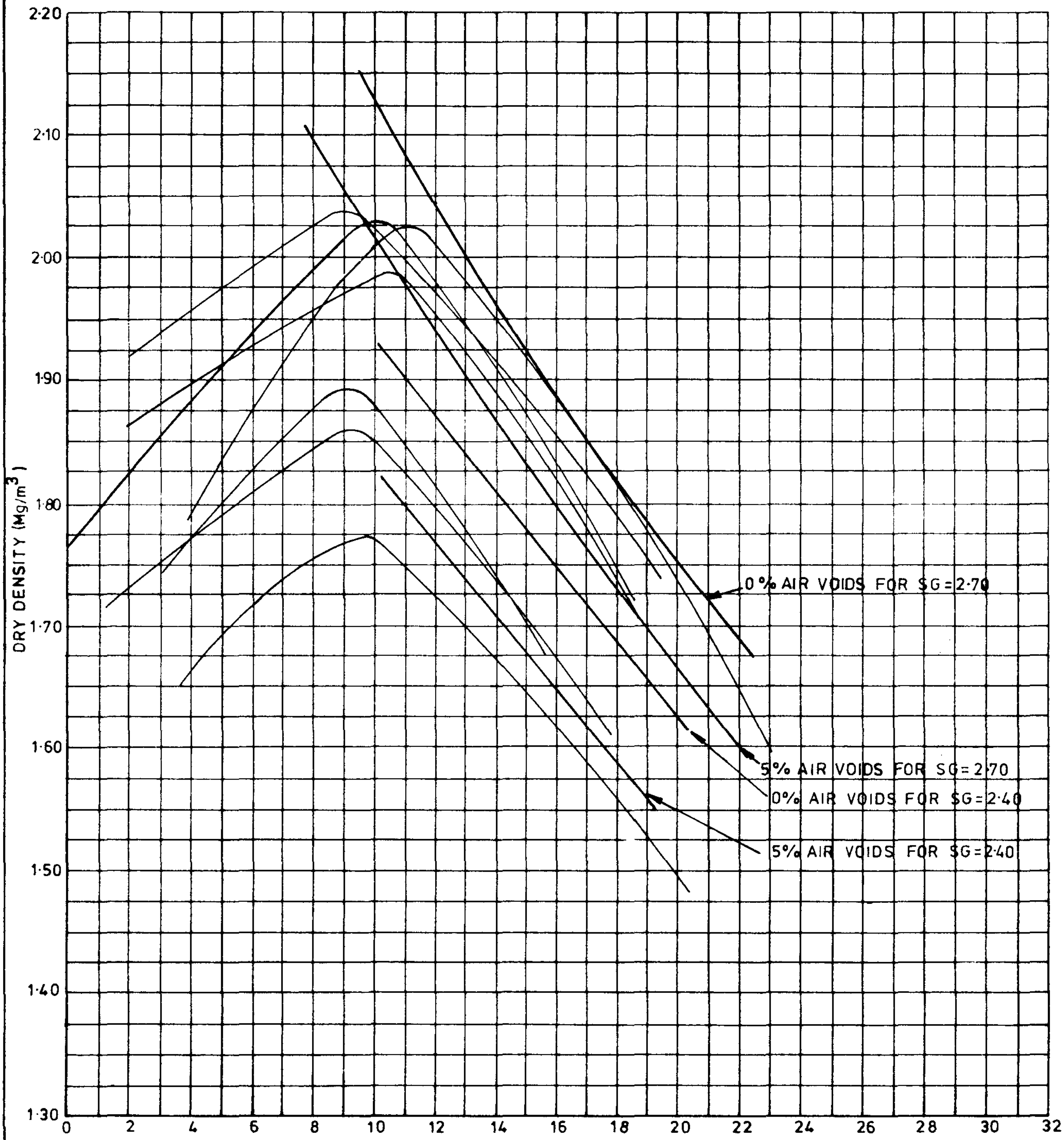
ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



Cheltenham Sands & Gravels (CSG)
1990b_T79, 0.90

A417 - MISSING LINK
SHEAR BOX TESTS
CHELTENHAM SANDS & GRAVELS

FIGURE: F3.10

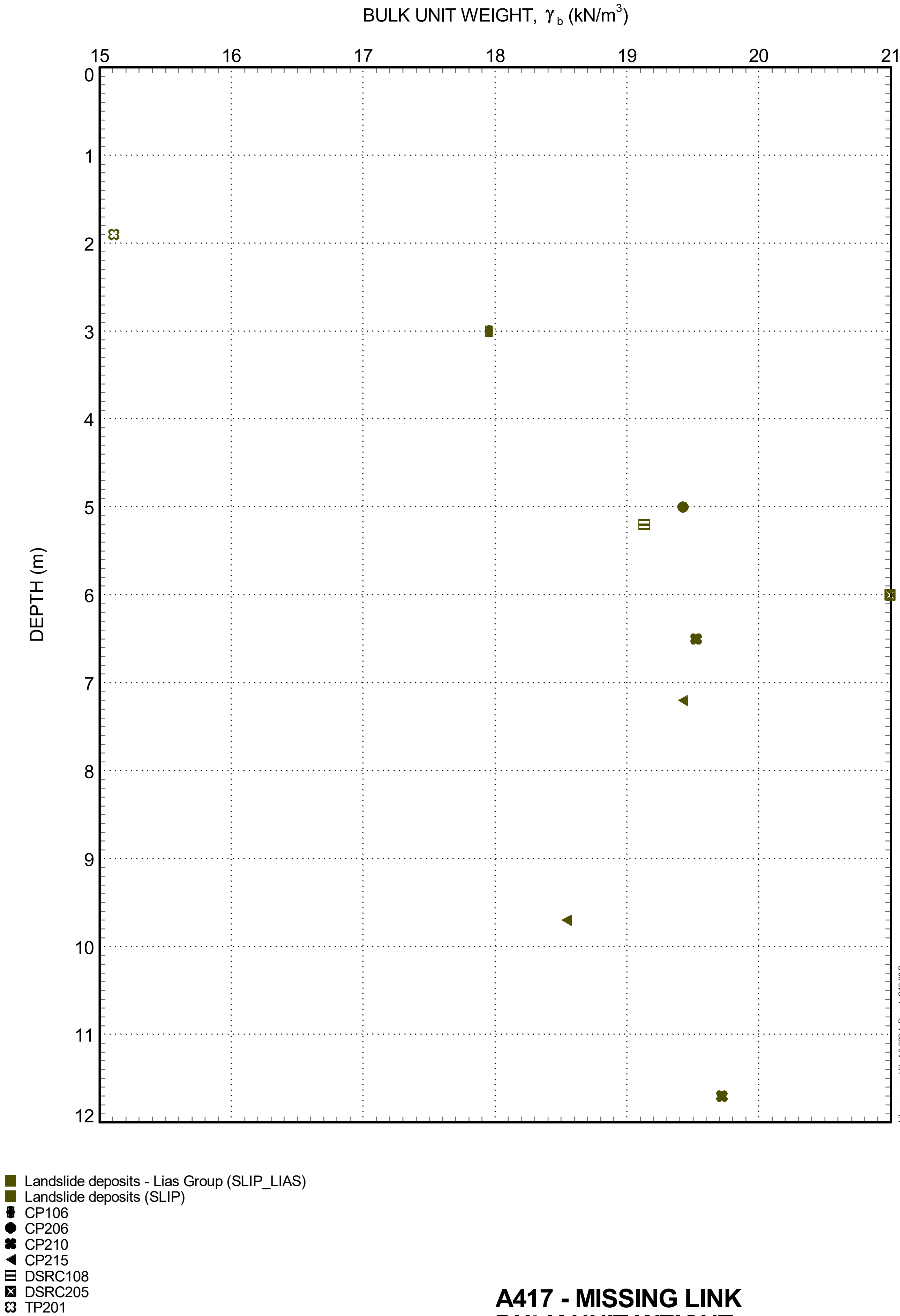


SPECIFIC GRAVITY – 2·70 (ASSUMED)
2·40 (MEASURED)

FIGURE: F3.11

Frank Graham Consulting Engineers	A417 BROCKWORTH BYPASS GEOTECHNICAL INTERPRETATIVE REPORT FAN GRAVEL : COMPOSITE COMPACTION PLOT			
THE DEPARTMENT OF TRANSPORT SOUTH WEST REGION DIRECTOR (CONSTRUCTION PROGRAMME) W.E. GALLAGHER B.Sc.(ENG) C.ENG. M.I.C.E	Job No CWH / 091073 / 024			Fig. No. 7g
	Scale NTS	Date APRIL 91	Drawn	Checked

F.4 Mass Movement Deposits



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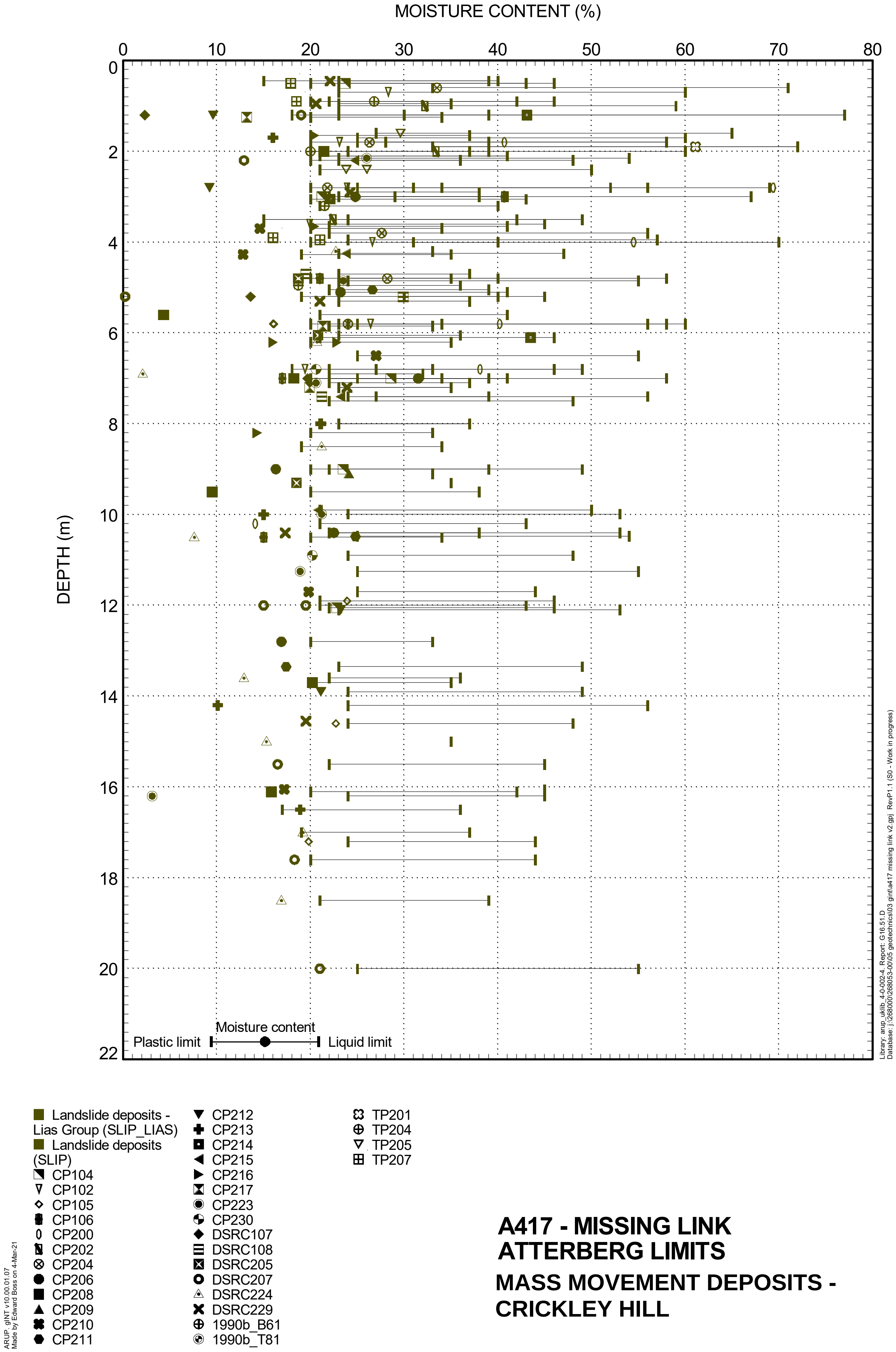
ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
BULK UNIT WEIGHT

MASS MOVEMENT DEPOSITS - CRICKLEY HILL

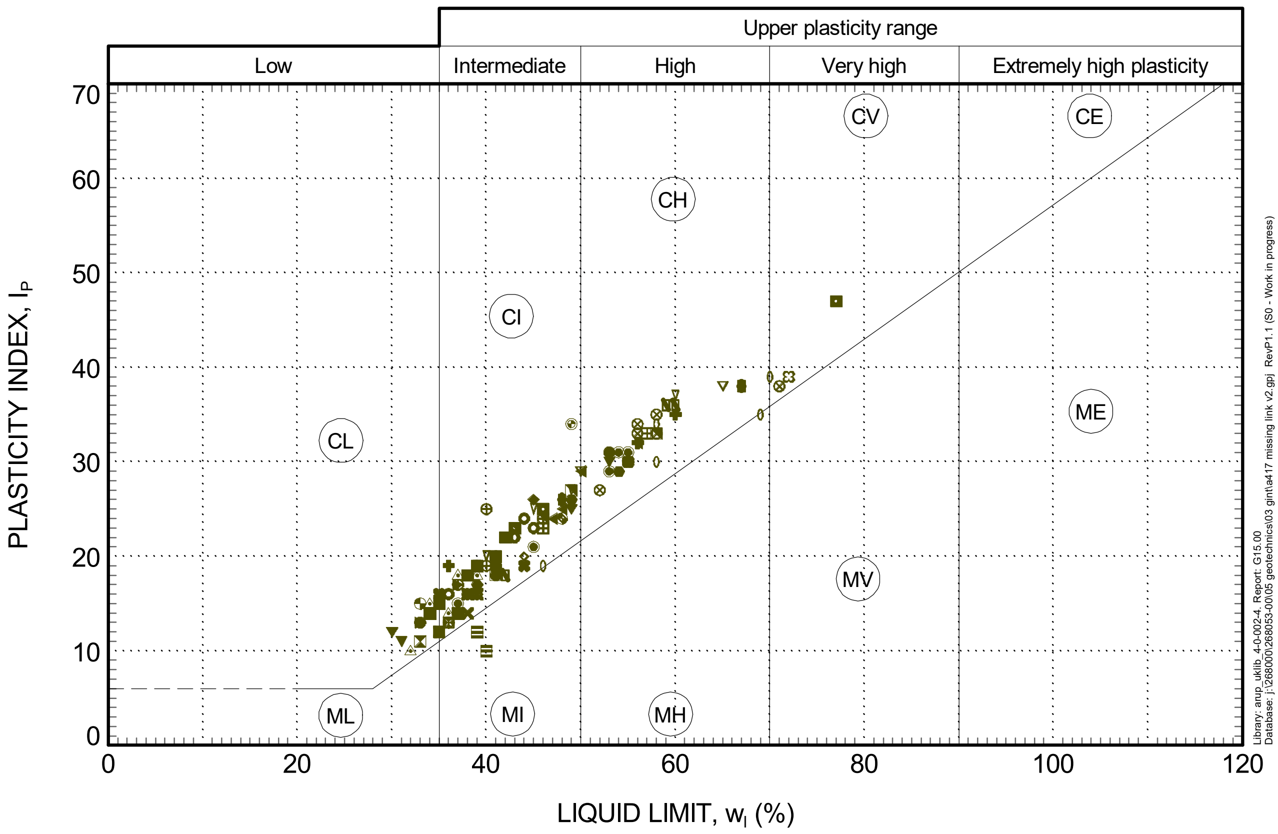
FIGURE: F4A.01



A417 - MISSING LINK
ATTERBERG LIMITS

MASS MOVEMENT DEPOSITS - CRICKLEY HILL

FIGURE: F4A.02



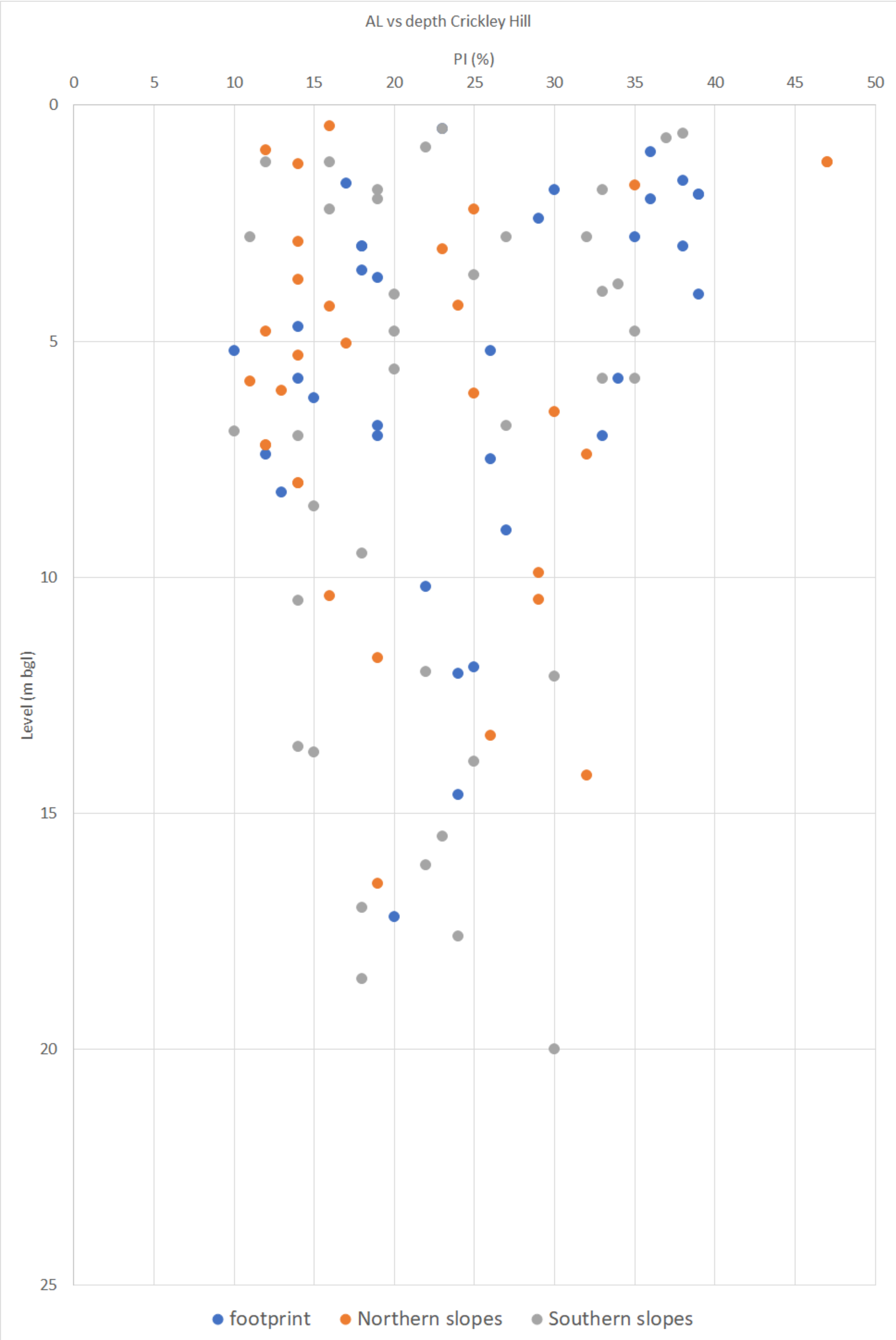
Landslide deposits - Lias Group (SLIP_LIAS)
Landslide deposits (SLIP)
CP104
CP102
CP105
CP106
CP200
CP202
CP204
CP206
CP208
CP210
CP211
CP212
CP213
CP214
CP215
CP216
CP217
CP223
CP230
DSRC107
DSRC108
DSRC205
DSRC207
DSRC224
DSRC229
1990b_B61
1990b_T81
TP201
TP204
TP205
TP207

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
PLASTICITY CHART

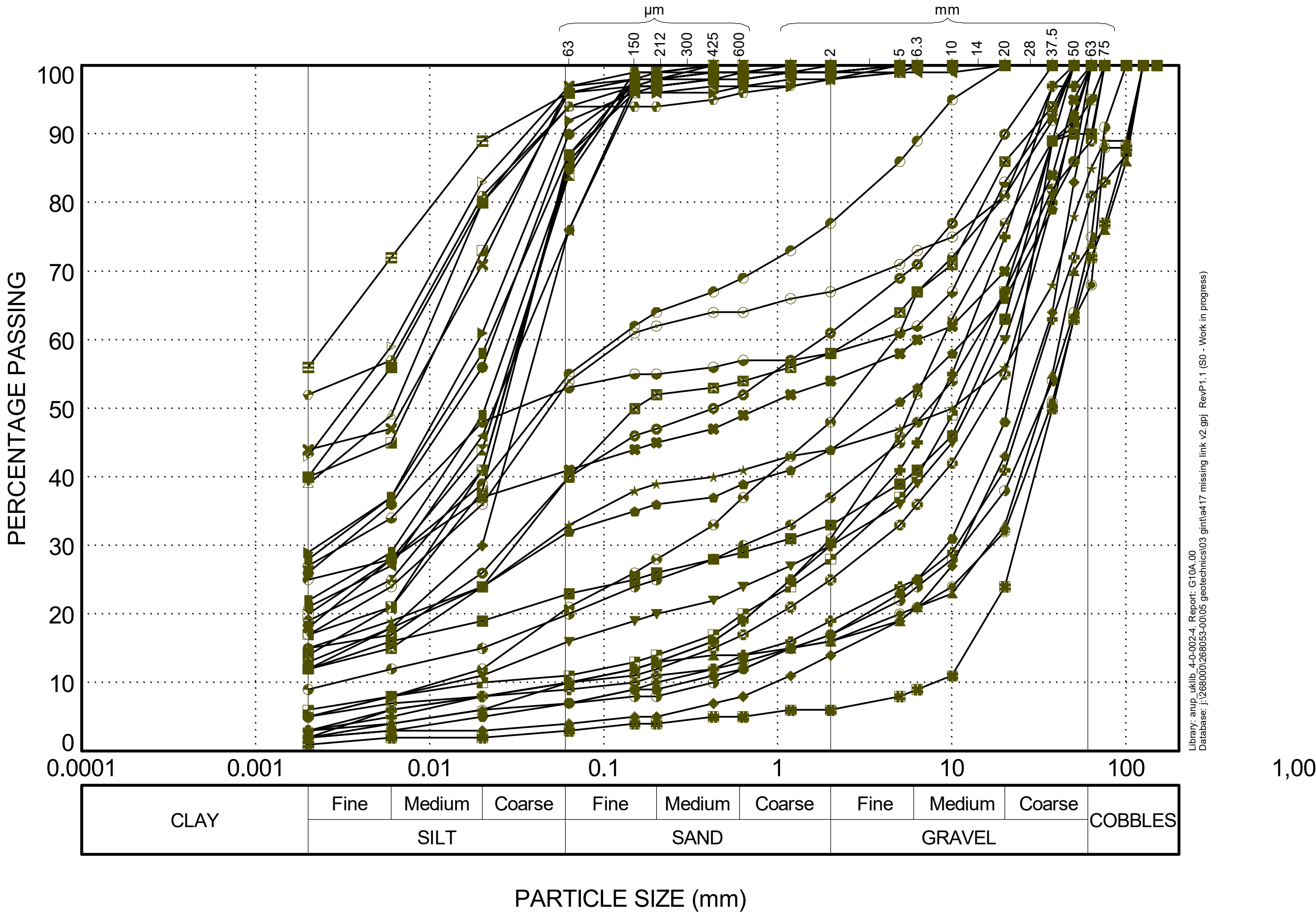
MASS MOVEMENT DEPOSITS - CRICKLEY HILL

FIGURE: F4A.03



A417 - MISSING LINK
PLASTICITY INDEX
MASS MOVEMENT DEPOSITS - CRICKLEY HILL

FIGURE: F4A.04

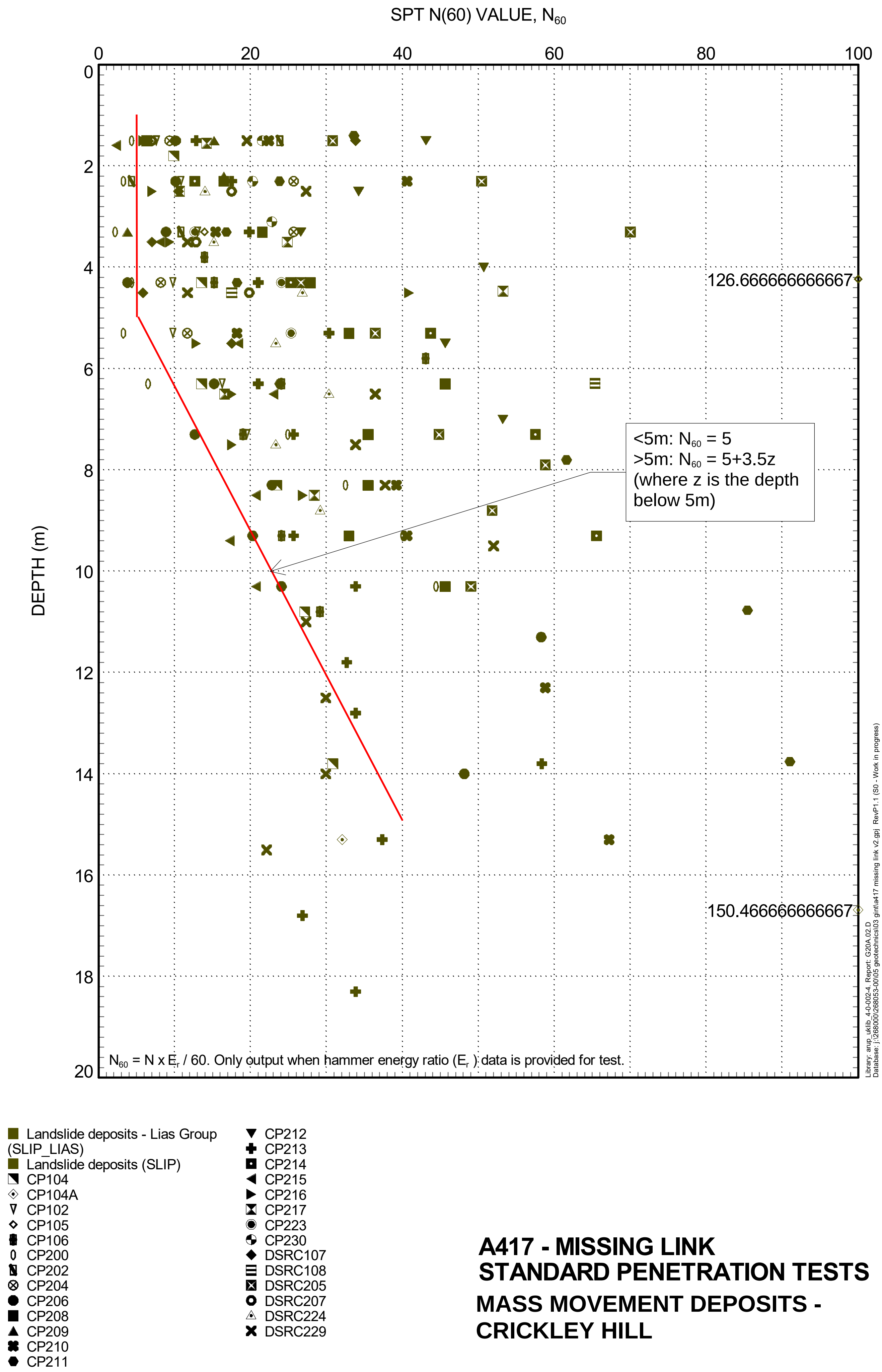


Landslide deposits - Lias Group (SLIP_LIAS)
Landslide deposits (SLIP)
CP104, 2.00, 5
CP104, 5.50, 14
CP105, 6.00, 24
CP106, 5.50, 21
CP200, 7.00, 21
CP200, 8.00, 24
CP200, 9.00, 27
CP206, 0.80, 3
CP206, 4.00, 18
CP208, 4.40, 13
CP208, 13.70, 31
CP209, 1.90, 7
CP210, 1.20, 5
CP211, 1.10, 8
CP211, 4.70, 14
CP212, 6.70, 18
CP213, 1.70, 5
CP213, 6.50, 18
CP213, 16.70, 45
CP214, 3.55, 10
CP214, 10.00, 30
CP215, 4.90, 18
CP215, 9.10, 35
CP216, 3.20, 10
CP217, 2.20, 7
DSRC107, 1.20, 8
DSRC107, 3.20, 14
DSRC108, 4.40, 14
DSRC205, 1.20, 5
DSRC205, 4.00, 12
DSRC205, 6.80, 18
DSRC207, 5.20, 17
DSRC224, 1.20, 5
DSRC224, 4.60, 14
DSRC224, 15.00, 34
DSRC229, 4.20, 18
TP201, 2.20, 4
TP204, 2.00, 6
TP205, 3.30, 9
TP207, 0.50, 2

A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
MASS MOVEMENT DEPOSITS - CRICKLEY HILL

FIGURE: F4A.05

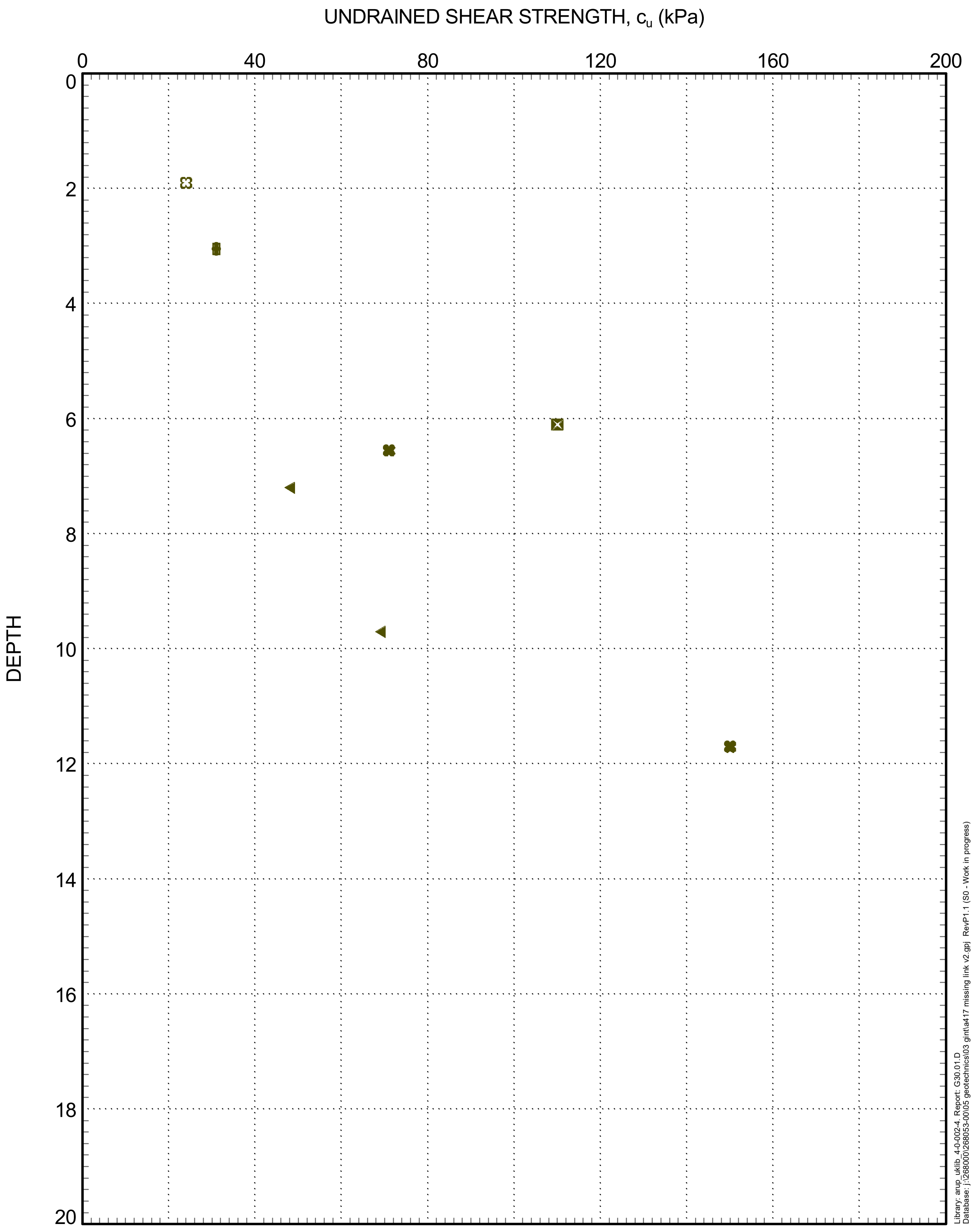
ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



A417 - MISSING LINK
STANDARD PENETRATION TESTS

MASS MOVEMENT DEPOSITS - CRICKLEY HILL

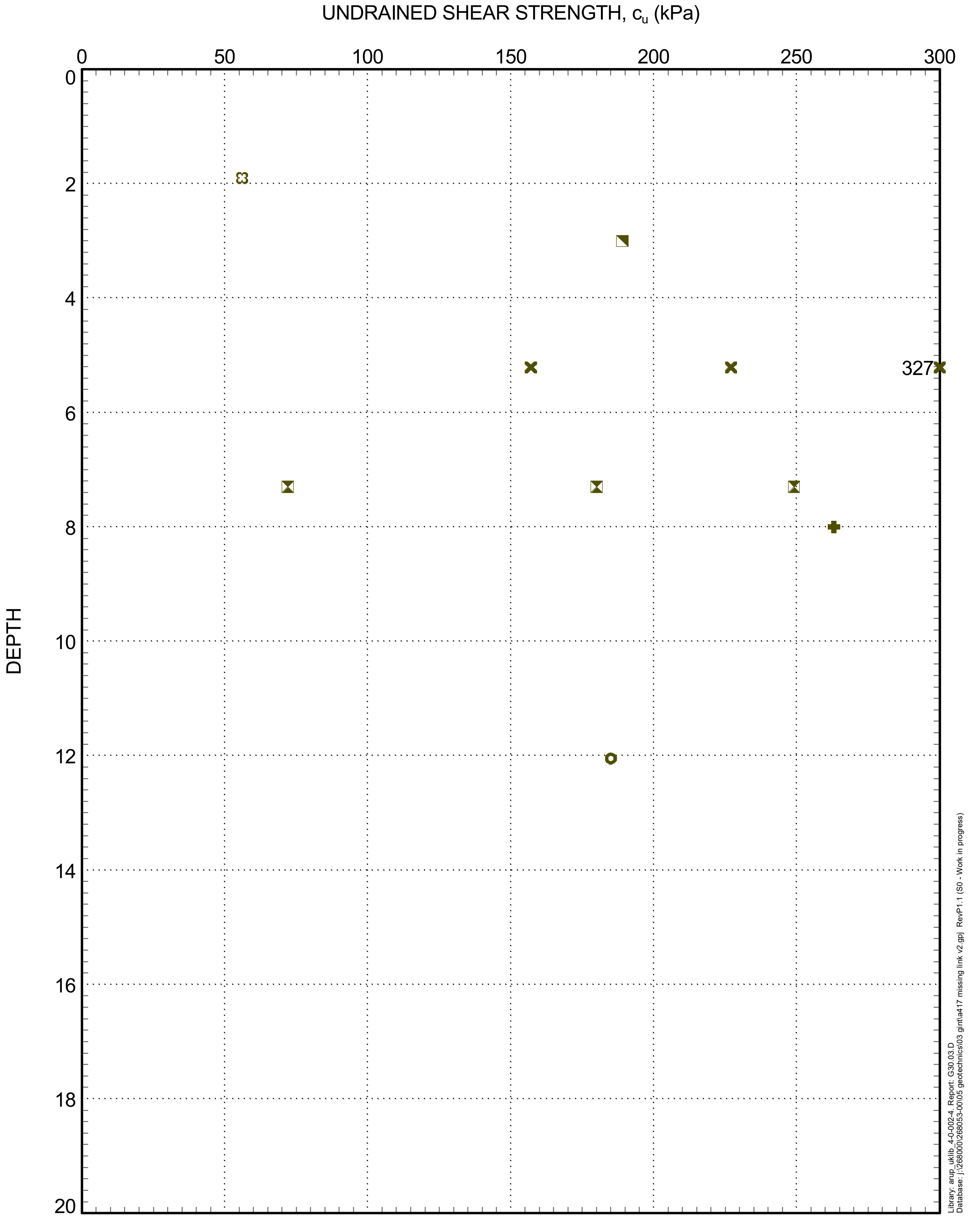
FIGURE: F4A.06



Landslide deposits - Lias Group (SLIP_LIAS)
Landslide deposits (SLIP)
CP106
CP210
CP215
DSRC205
TP201

A417 - MISSING LINK
TRIAXIAL UNDRAINED SHEAR STRENGTH

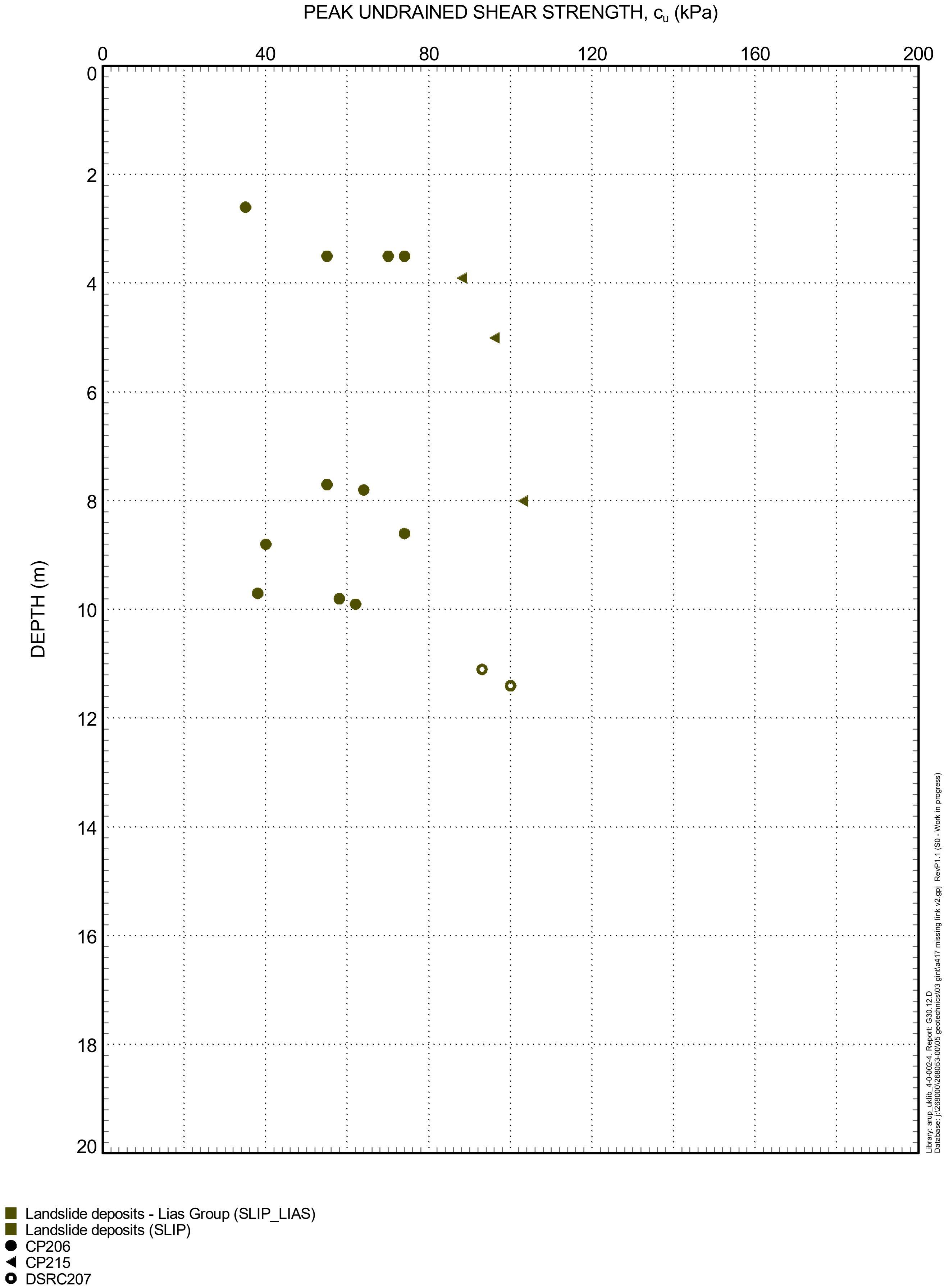
MASS MOVEMENT DEPOSITS - CRICKLEY HILL
FIGURE: F4A.07



Landslide deposits - Lias Group (SLIP_LIAS)
Landslide deposits (SLIP)
CP104
CP213
CP217
DSRC207
DSRC229
TP201

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
CONSOLIDATED TRIAXIAL
UNDRAINED SHEAR STRENGTH
MASS MOVEMENT DEPOSITS -
CRICKLEY HILL
FIGURE: F4A.08



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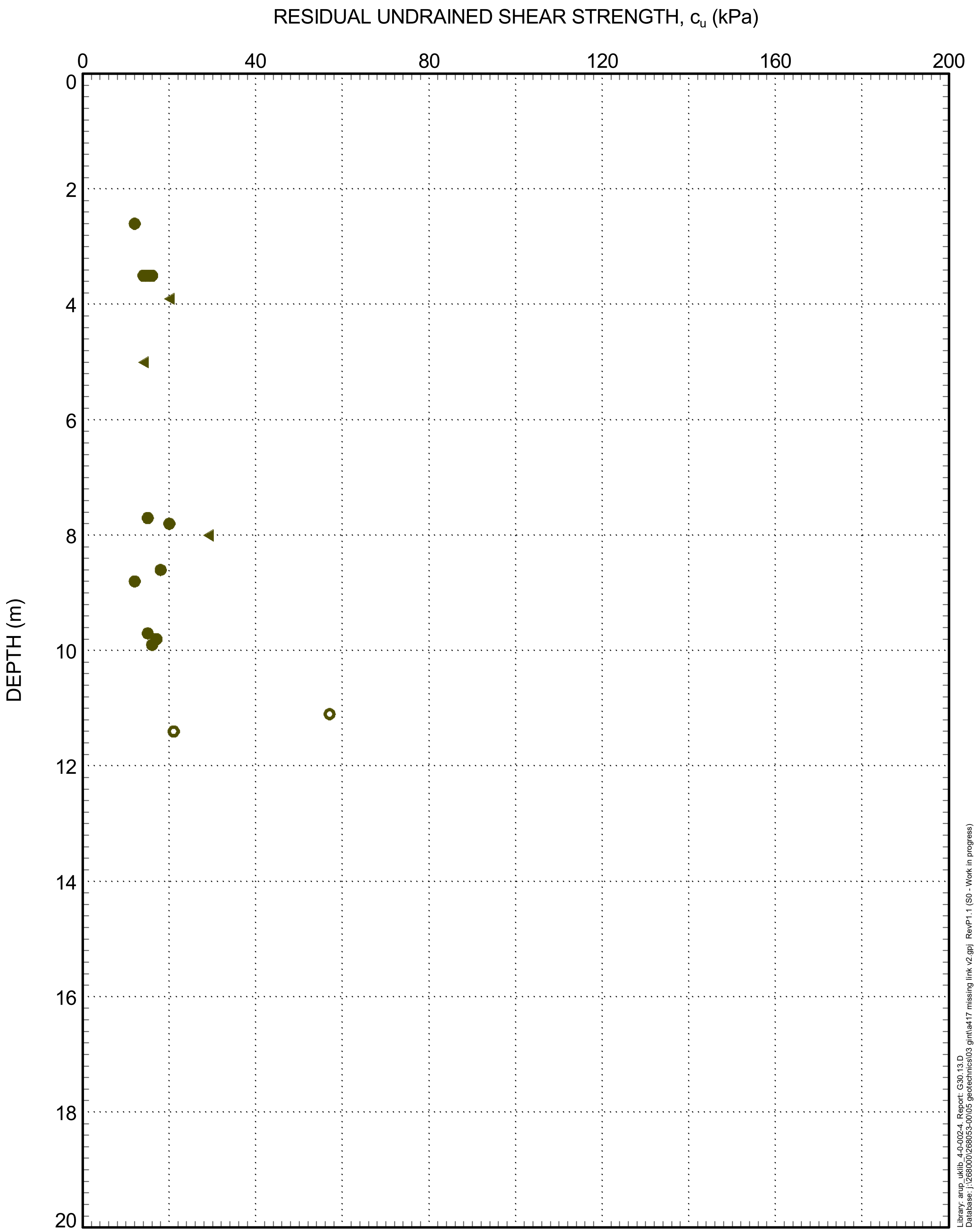
ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM HAND VANE

MASS MOVEMENT DEPOSITS - CRICKLEY HILL
FIGURE: F4A.09



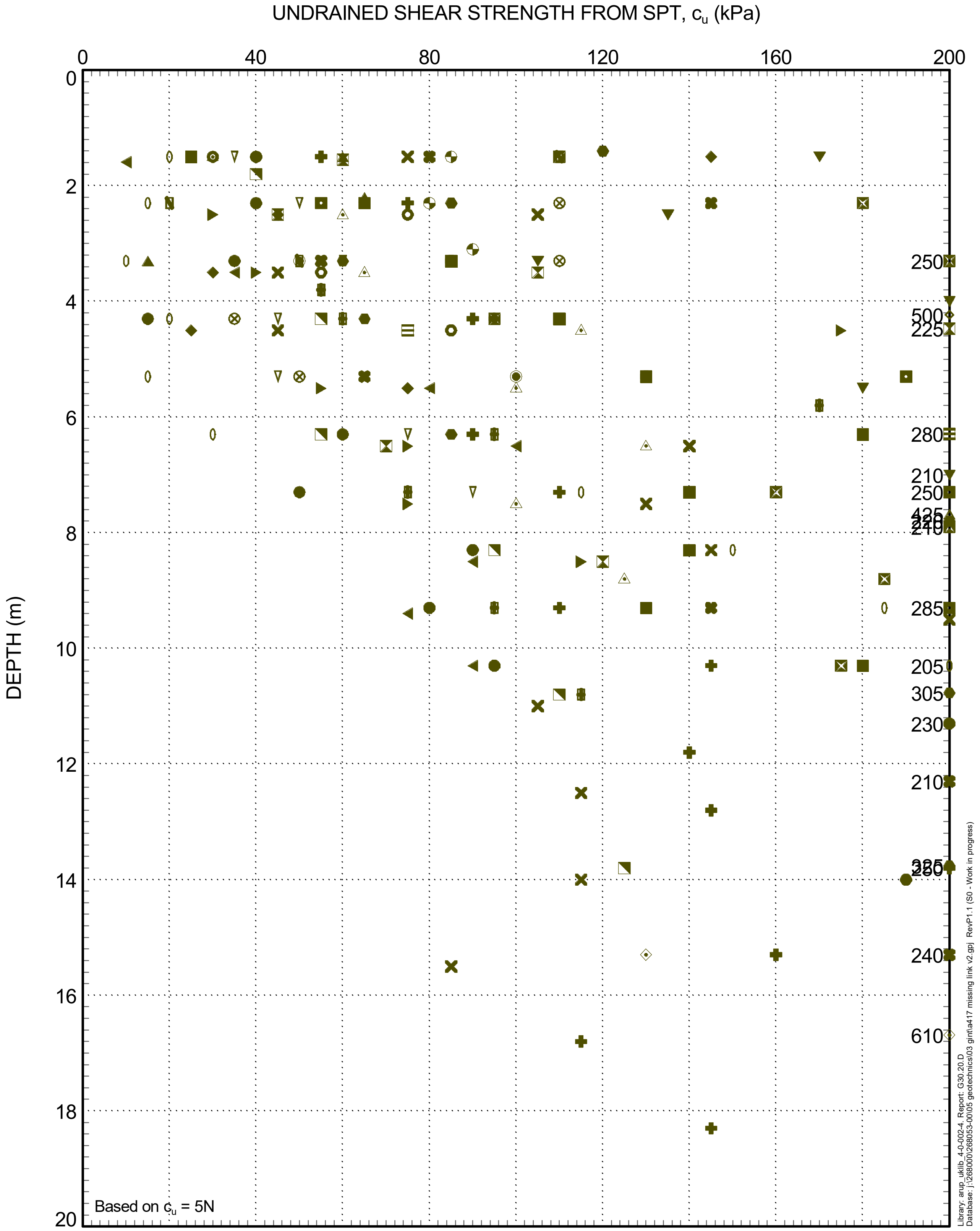
Library: arup_uklib_4-0-002-4. Report: G30.13.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

■ Landslide deposits - Lias Group (SLIP_LIAS)
■ Landslide deposits (SLIP)
● CP206
◀ CP215
○ DSRC207

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM HAND VANE

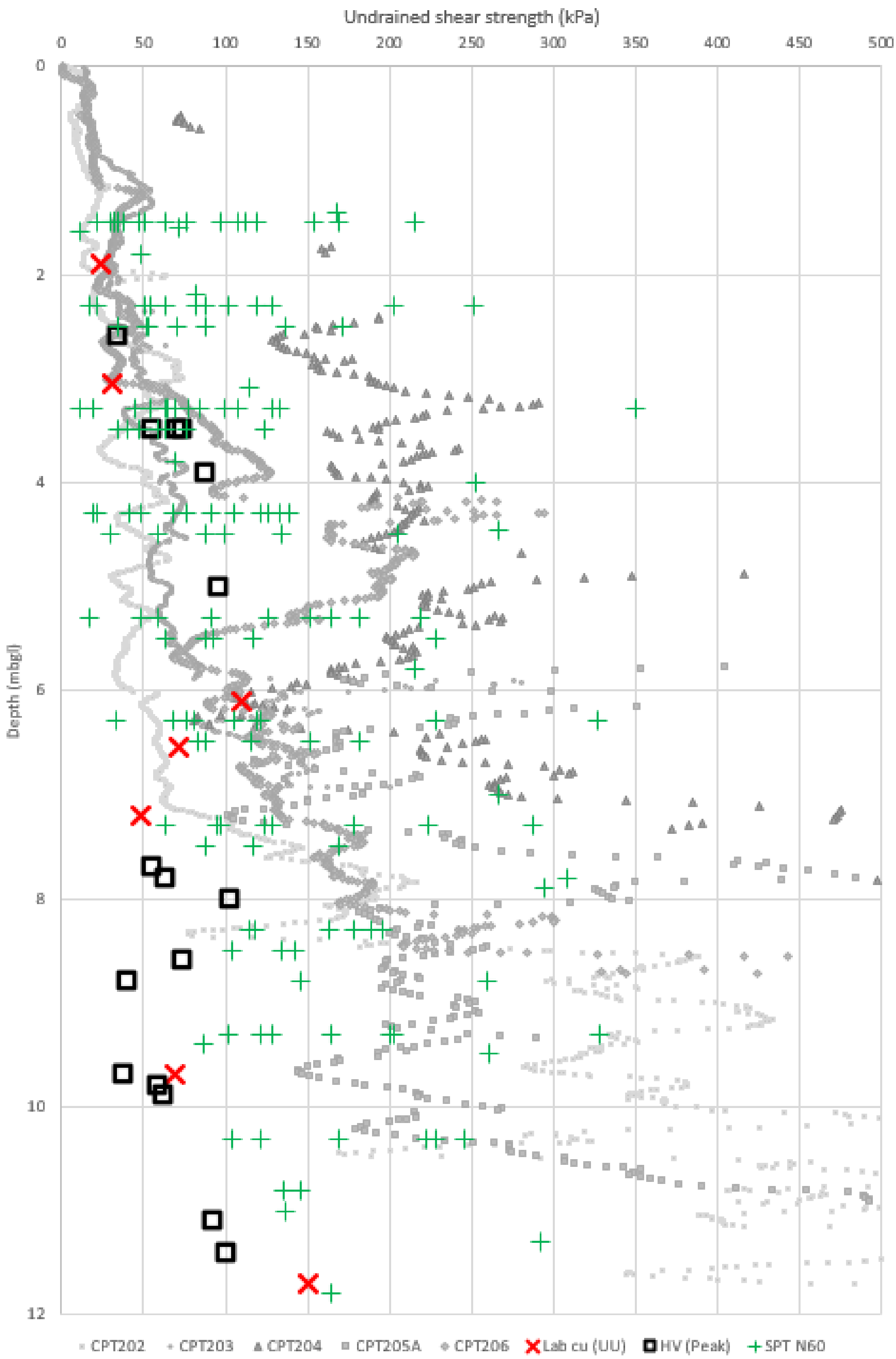
MASS MOVEMENT DEPOSITS - CRICKLEY HILL
FIGURE: F4A.10



A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM SPT

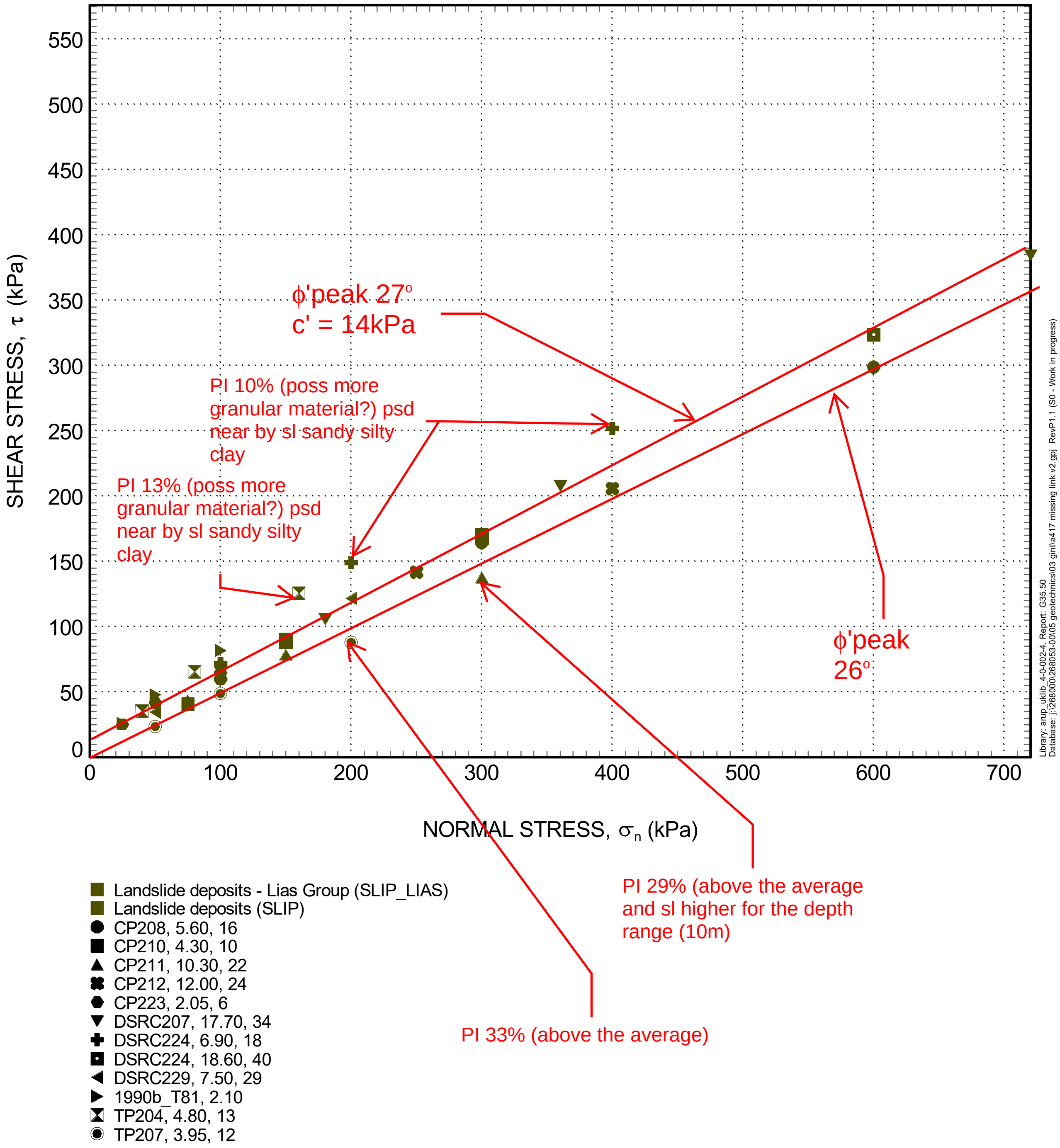
MASS MOVEMENT DEPOSITS - CRICKLEY HILL

FIGURE: F4A.11



A417 - MISSING LINK
COMPOSITE UNDRAINED SHEAR STRENGTH PLOT

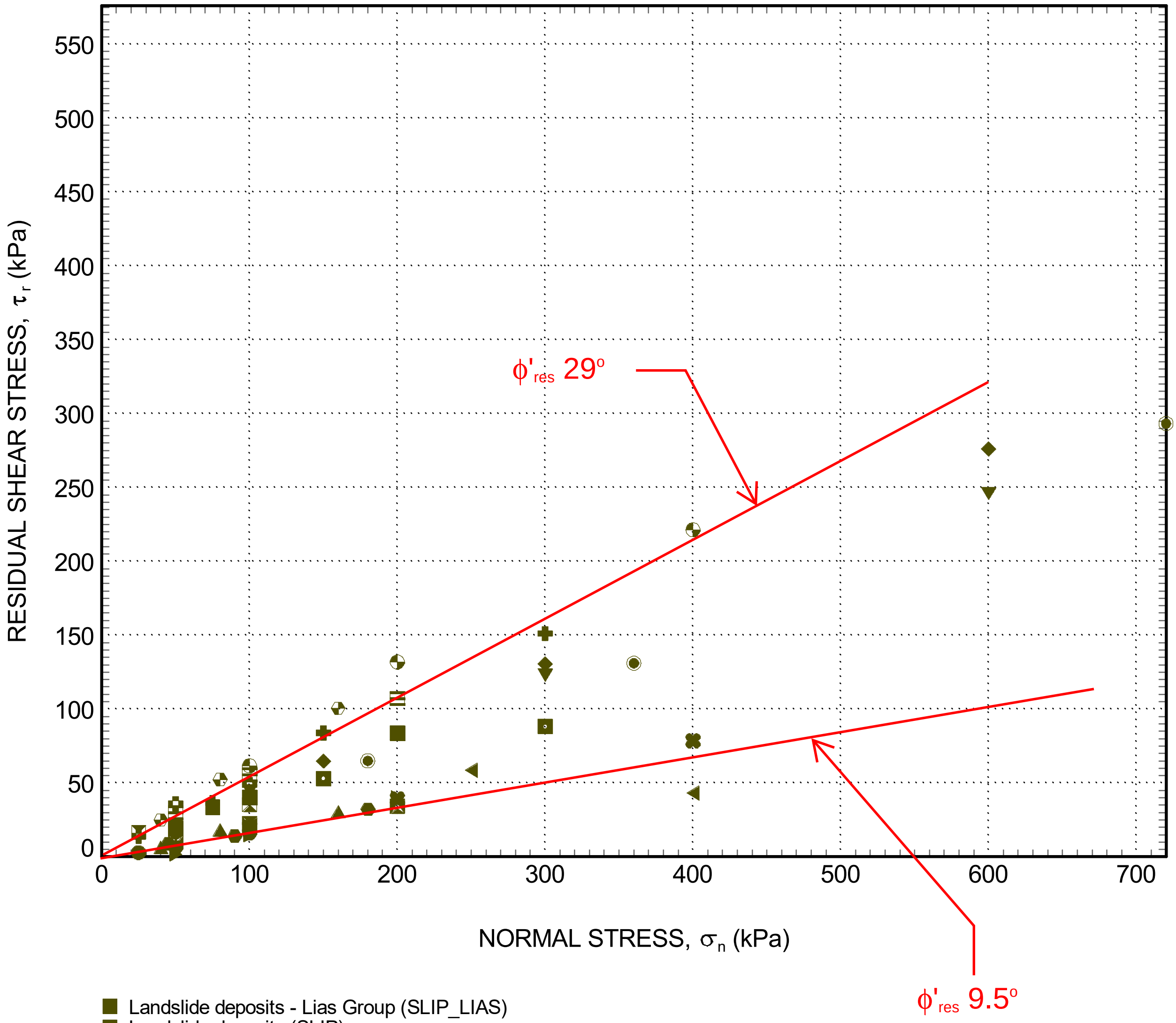
MASS MOVEMENT DEPOSITS - CRICKLEY HILL
FIGURE: F4A.12



A417 - MISSING LINK
SHEAR BOX TESTS

MASS MOVEMENT DEPOSITS - CRICKLEY HILL
FIGURE: F4A.13

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

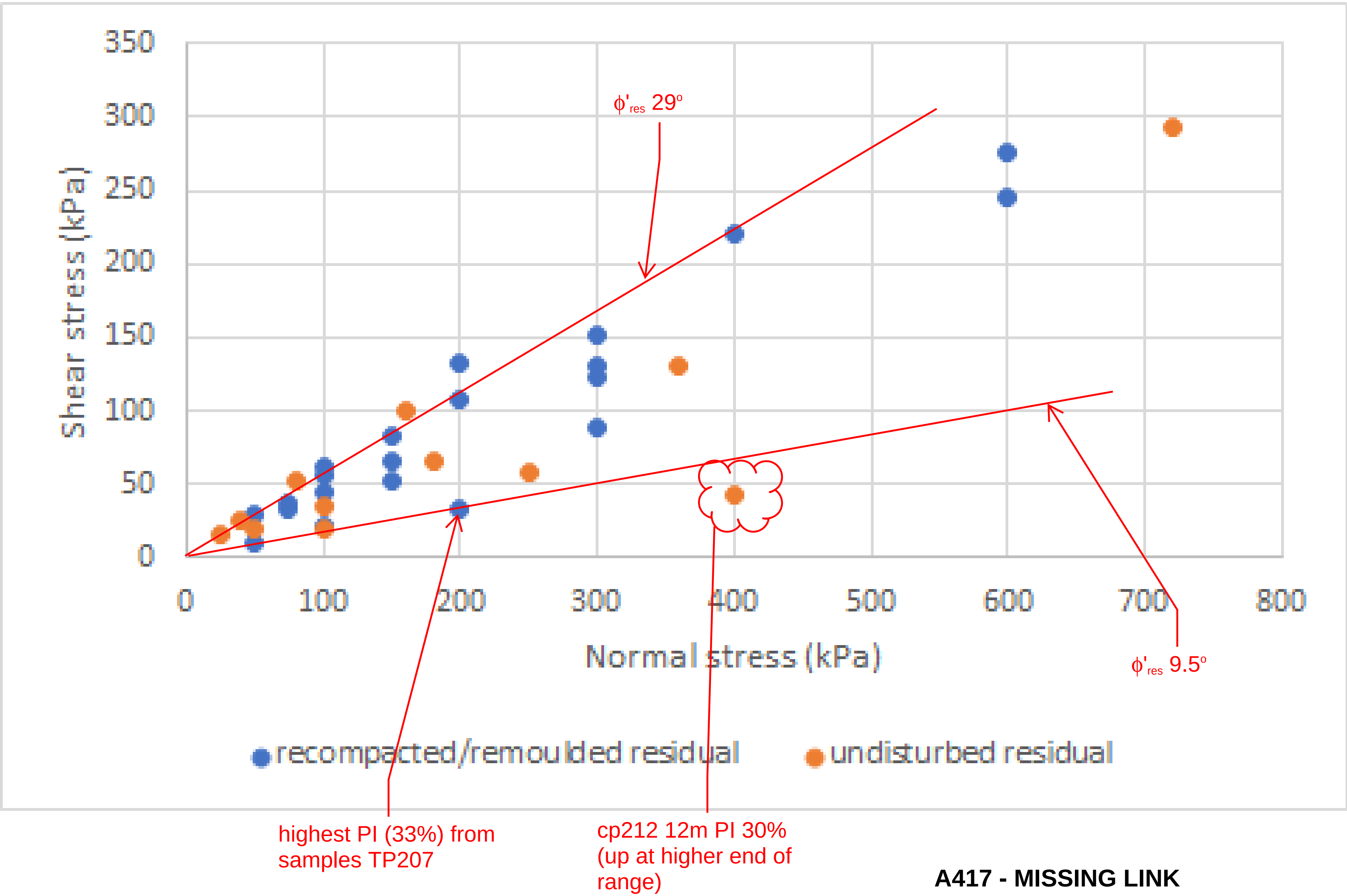


- Landslide deposits - Lias Group (SLIP_LIAS)
- Landslide deposits (SLIP)
- CP102, 2.50, 8
- CP102, 4.90, 14
- CP200, 4.00, 12
- CP200, 10.35, 29
- CP204, 4.50, 17
- CP208, 5.60, 16
- CP210, 4.30, 10
- CP211, 10.30, 22
- CP212, 12.00, 24
- CP215, 2.20, 7
- CP223, 2.05, 6
- DSRC207, 17.70, 34
- DSRC224, 6.90, 18
- DSRC224, 18.60, 40
- DSRC229, 7.50, 29
- 1990b_T81, 2.10
- TP204, 4.80, 13
- TP207, 3.95, 12

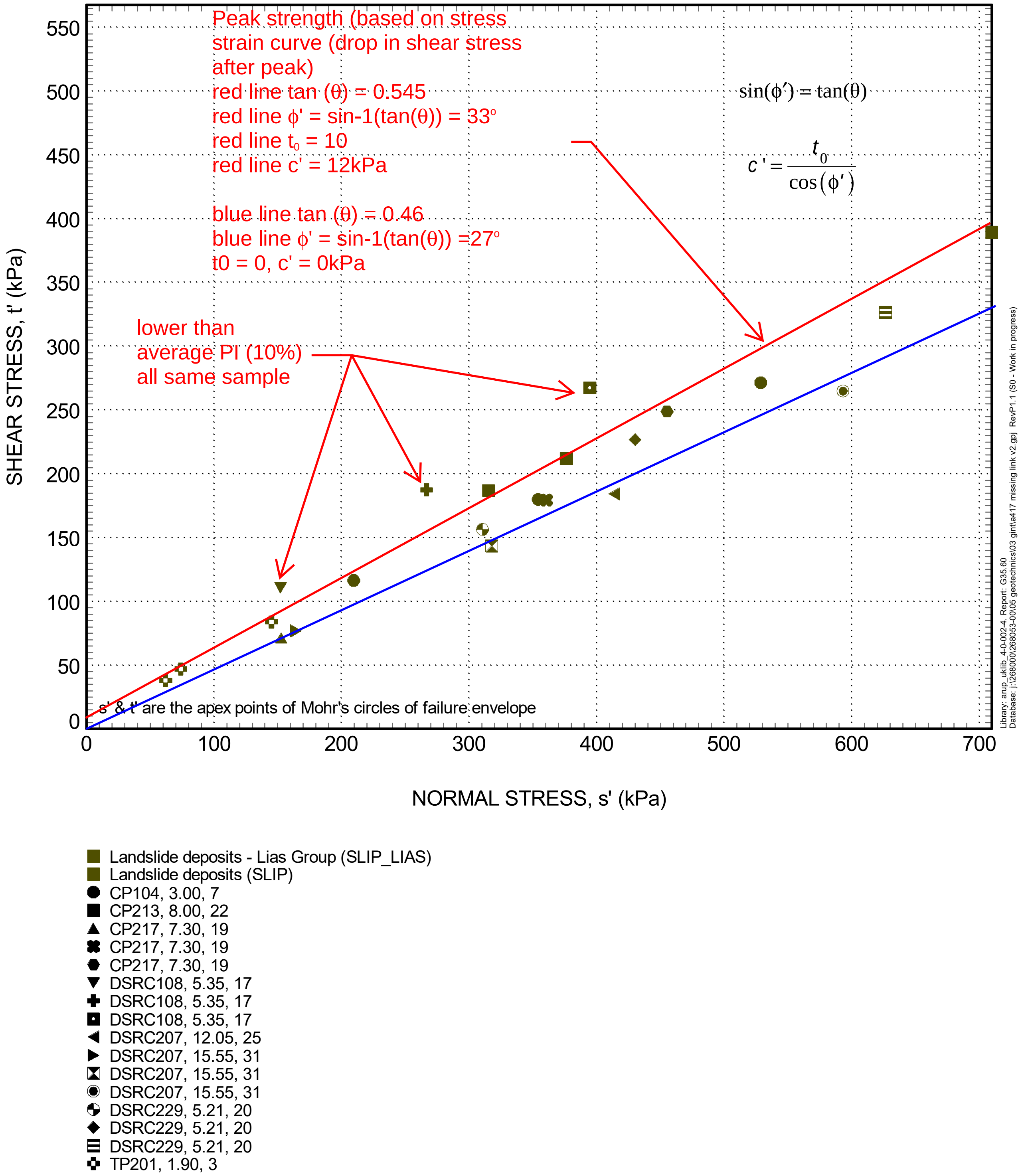
ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
SHEAR BOX TESTS

MASS MOVEMENT DEPOSITS -
CRICKLEY HILL
FIGURE: F4A.14



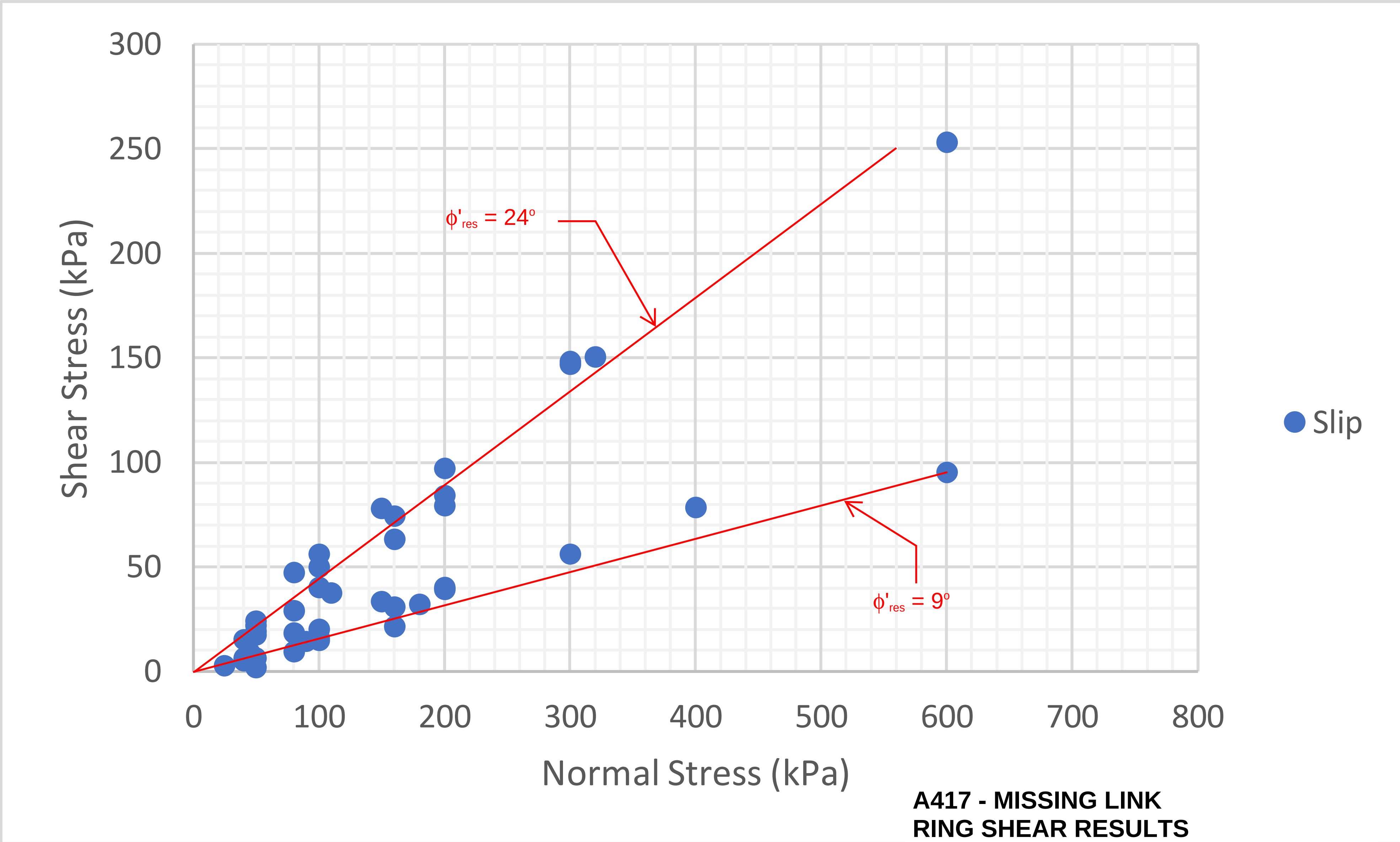
A417 - MISSING LINK
SHEAR BOX TEST ONLY
MASS MOVEMENT DEPOSITS -
CRICKLEY HILL
FIGURE: F4A.15



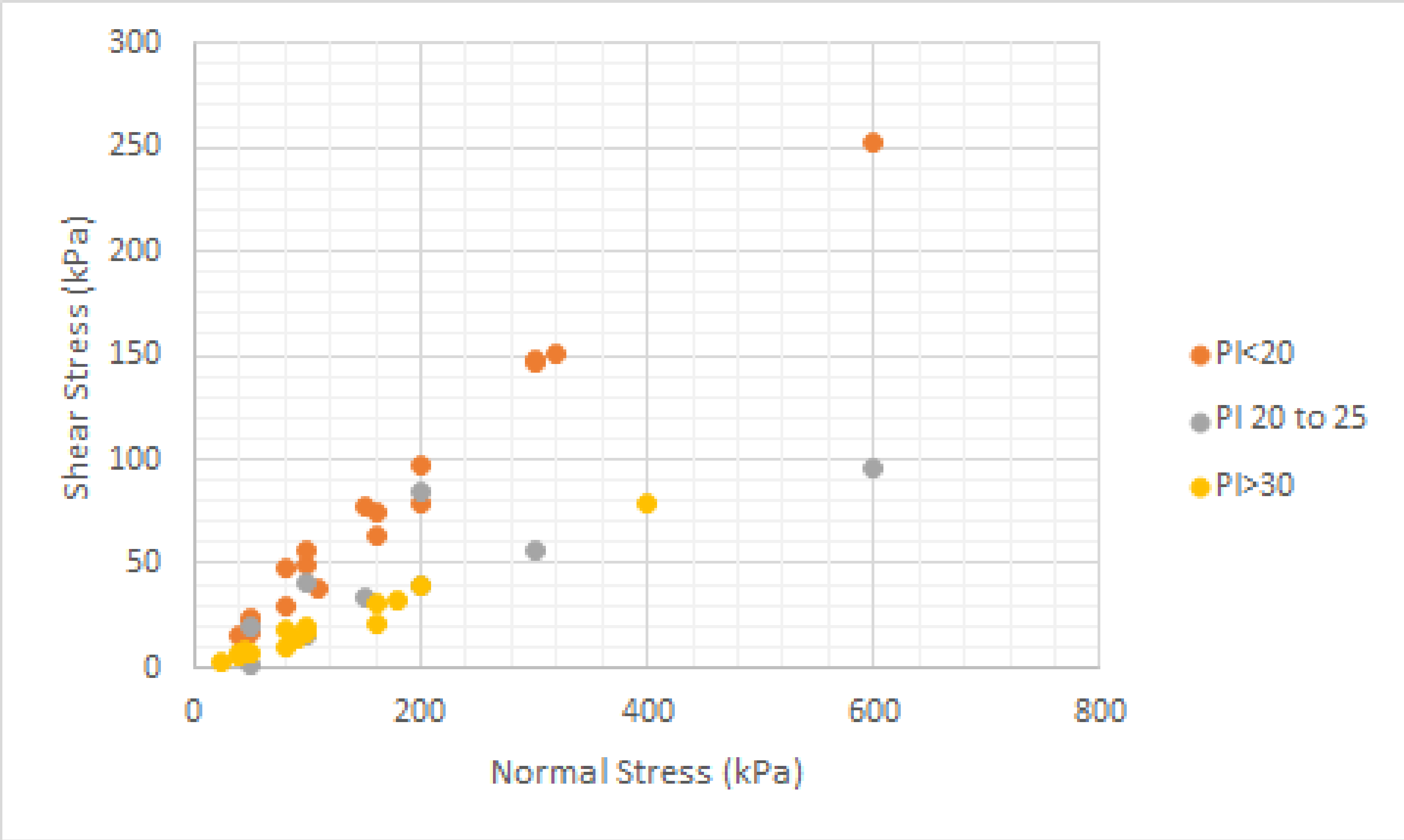
A417 - MISSING LINK
TRIAXIAL T' V S'

MASS MOVEMENT DEPOSITS - CRICKLEY HILL
FIGURE: F4A.16

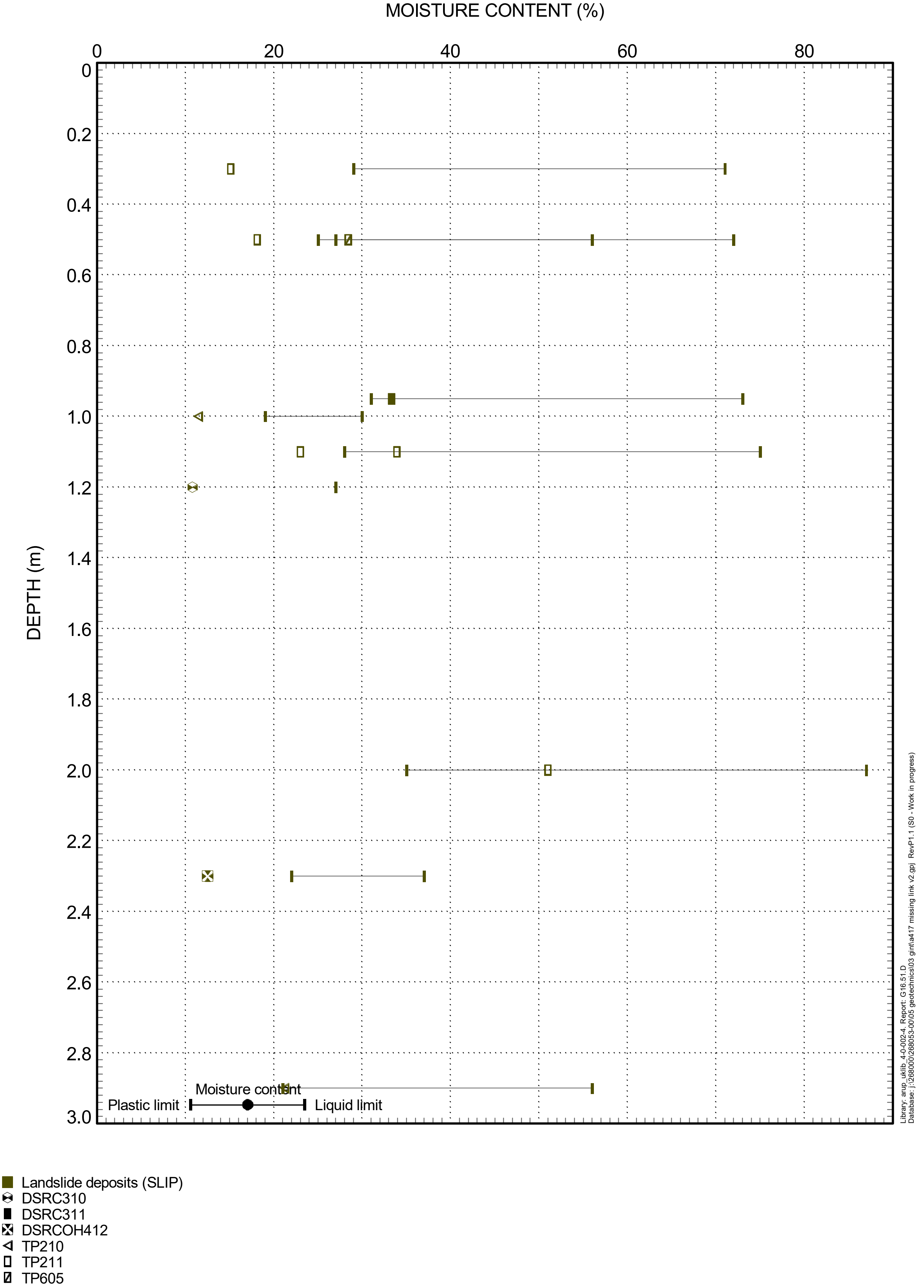
ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



A417 - MISSING LINK
RING SHEAR RESULTS
MASS MOVEMENT DEPOSITS -
CRICKLEY HILL
FIGURE: F4A.17



A417 - MISSING LINK
RING SHEAR SPLIT BY PLASTICITY INDEX
MASS MOVEMENT DEPOSITS - CRICKLEY HILL
FIGURE: F4A.18

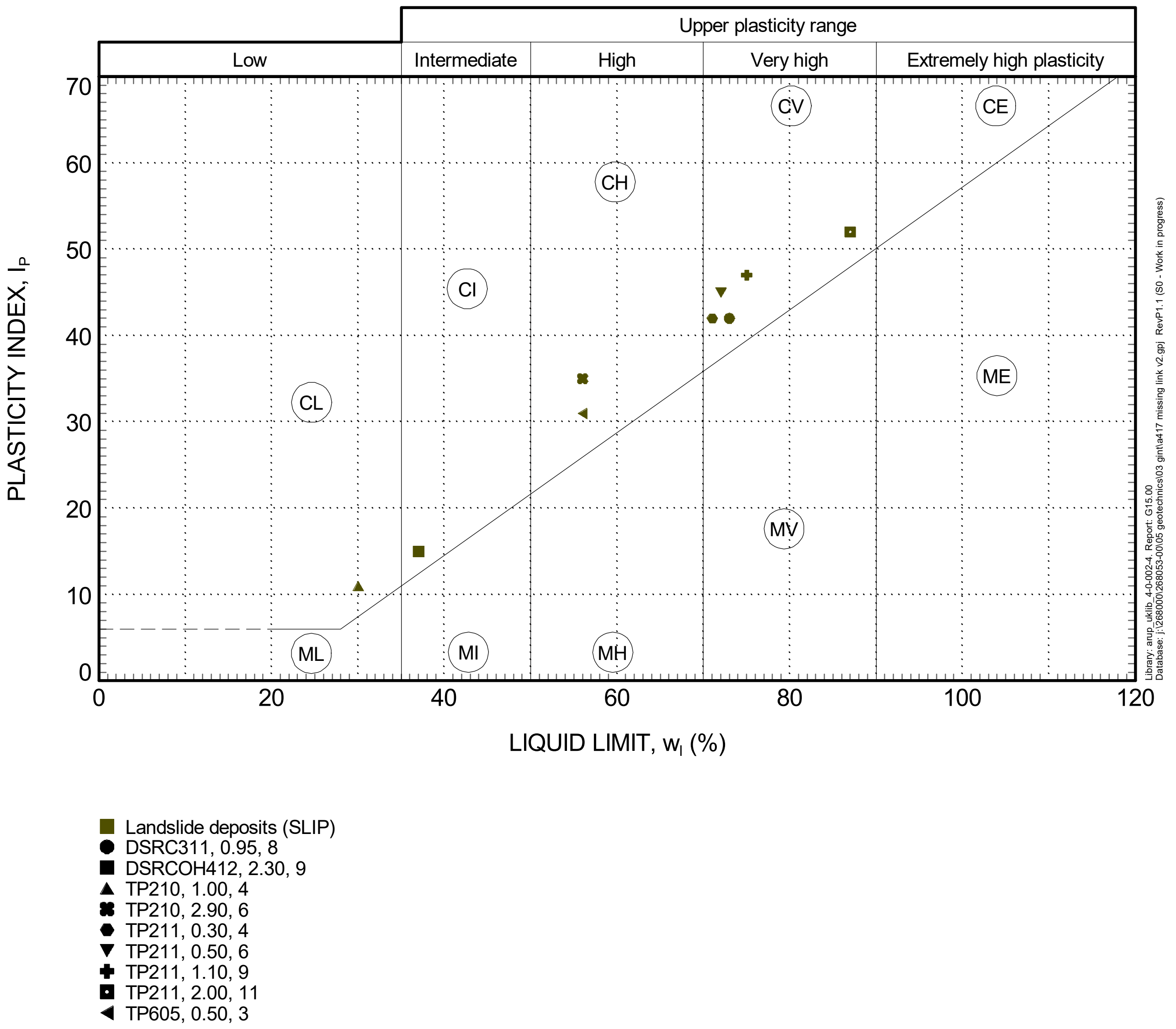


ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ATTERBERG LIMITS

MASS MOVEMENT DEPOSITS - SHAB HILL

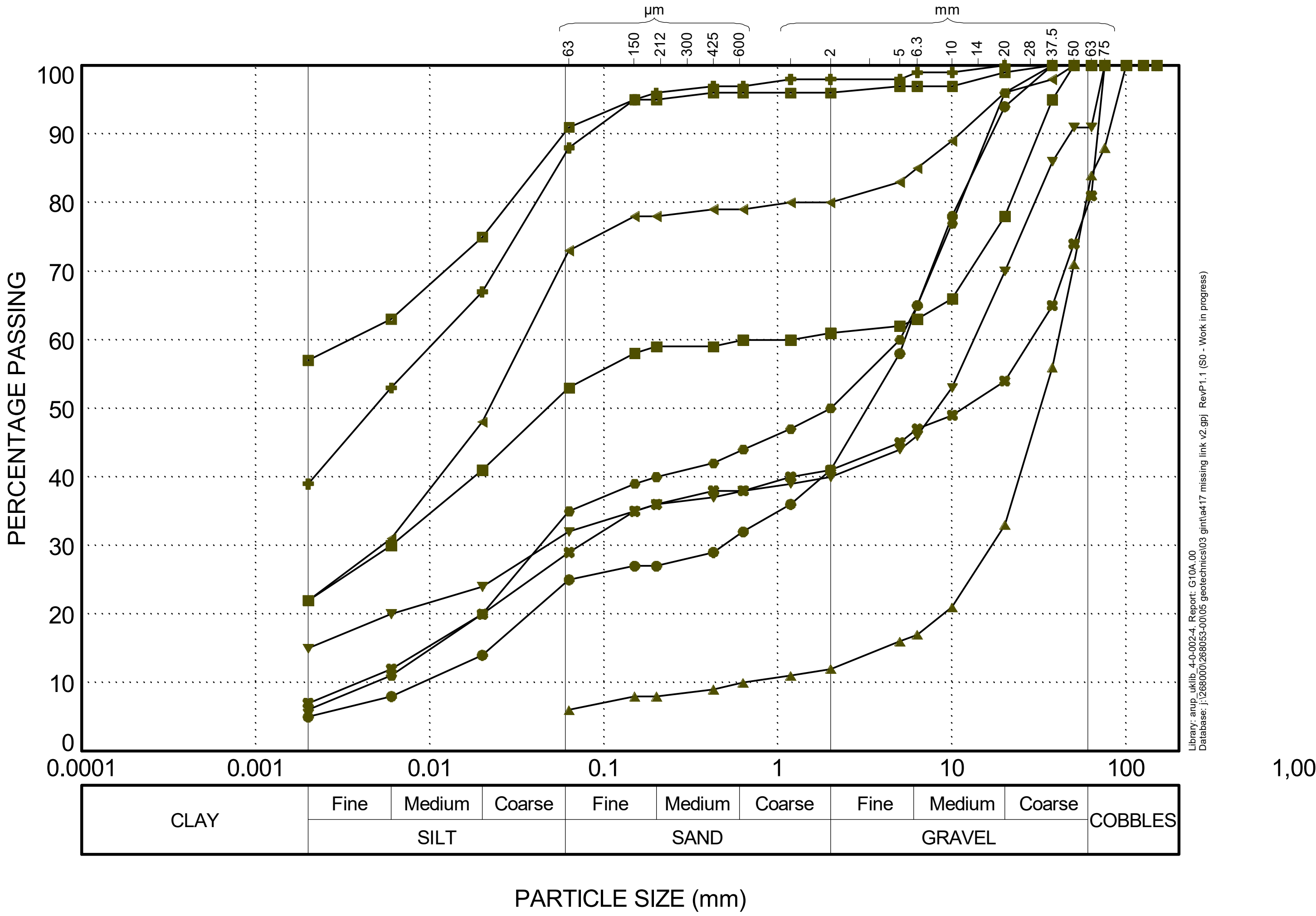
FIGURE: F4B.01



A417 - MISSING LINK
PLASTICITY CHART

MASS MOVEMENT DEPOSITS - SHAB HILL

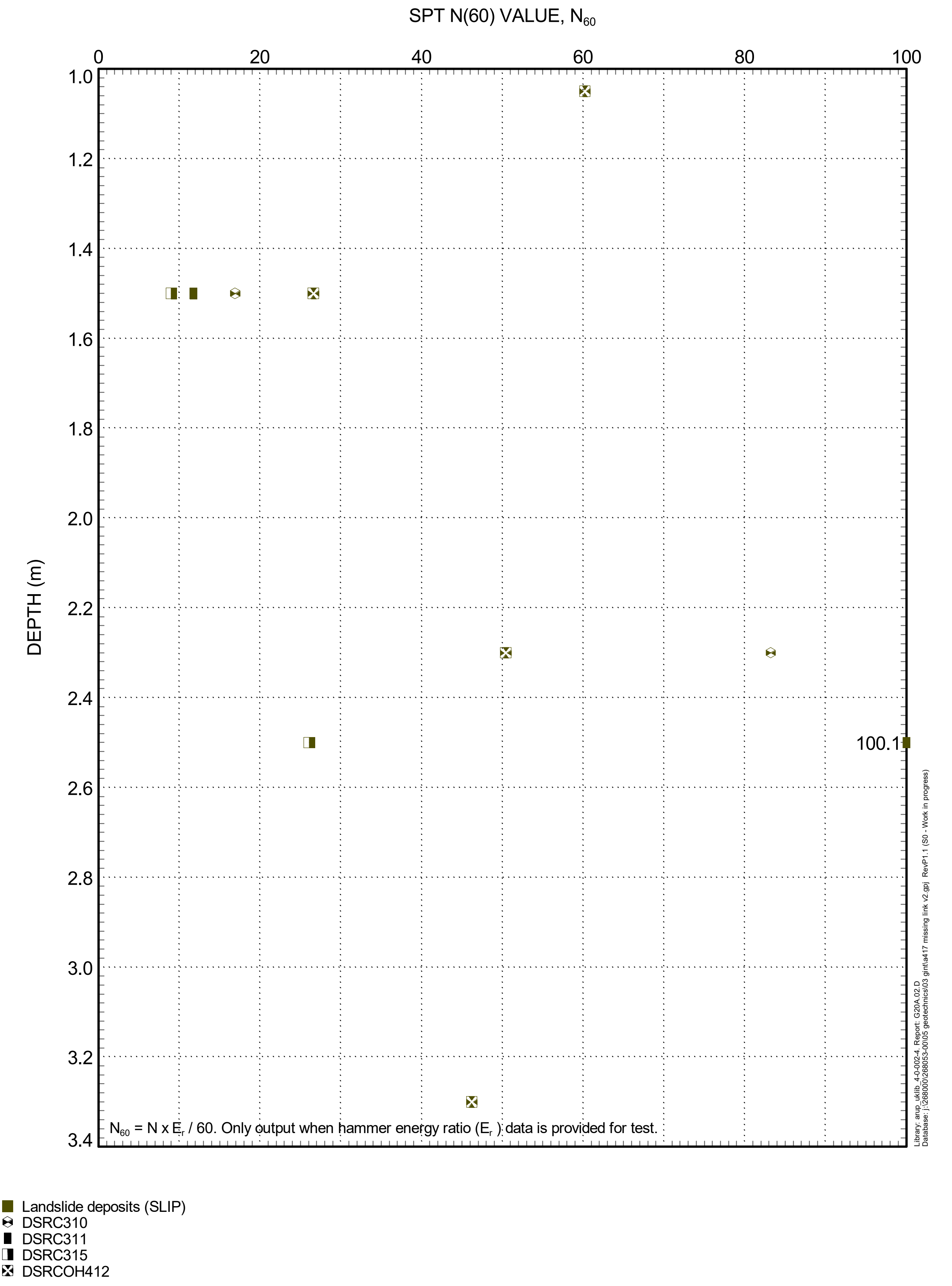
FIGURE: F4B.02



■ Landslide deposits (SLIP)
● DSRC310, 1.00, 7
■ DSRC311, 0.95, 7
▲ DSRCOH412, 1.20, 6
✖ DSRCOH412, 3.10, 10
⬢ TP210, 1.00, 4
▼ TP211, 0.30, 3
✚ TP211, 1.00, 7
◘ TP603, 1.00, 3
◀ TP605, 0.50, 3

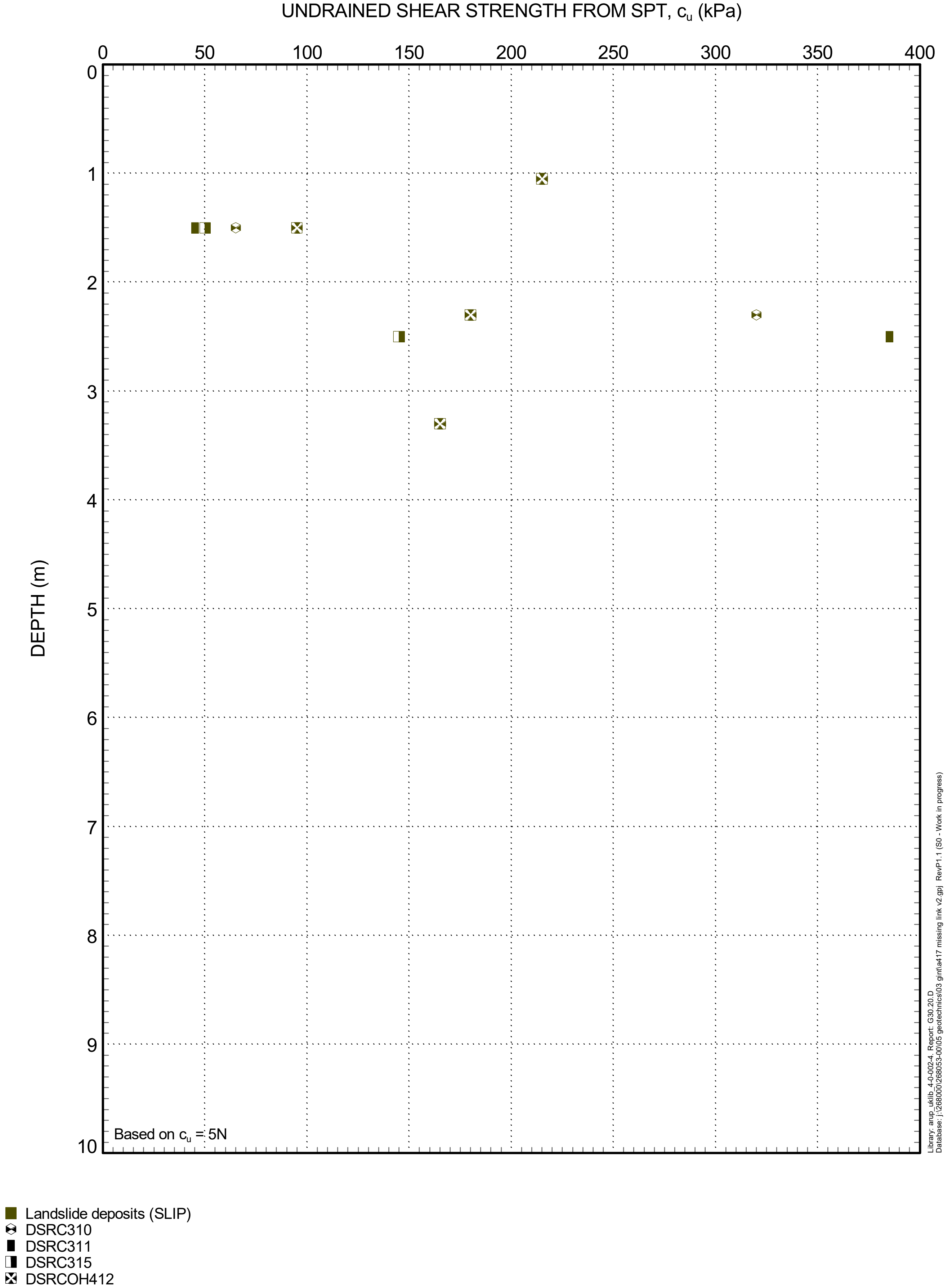
ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
MASS MOVEMENT DEPOSITS - SHAB HILL
FIGURE: F4B.03



ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
STANDARD PENETRATION TESTS
MASS MOVEMENT DEPOSITS - SHAB HILL
FIGURE: F4B.04

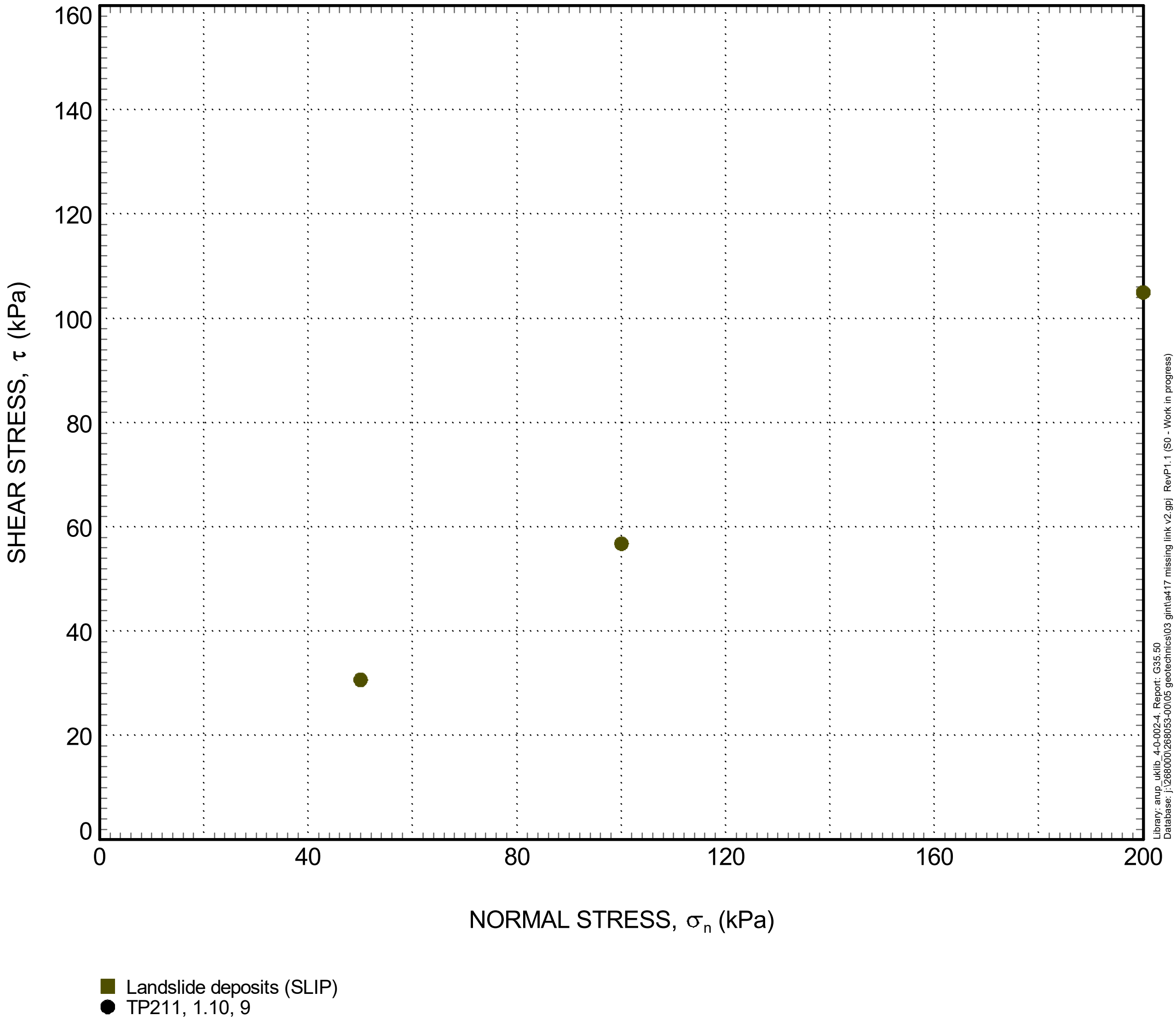


ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM SPT

MASS MOVEMENT DEPOSITS - SHAB HILL

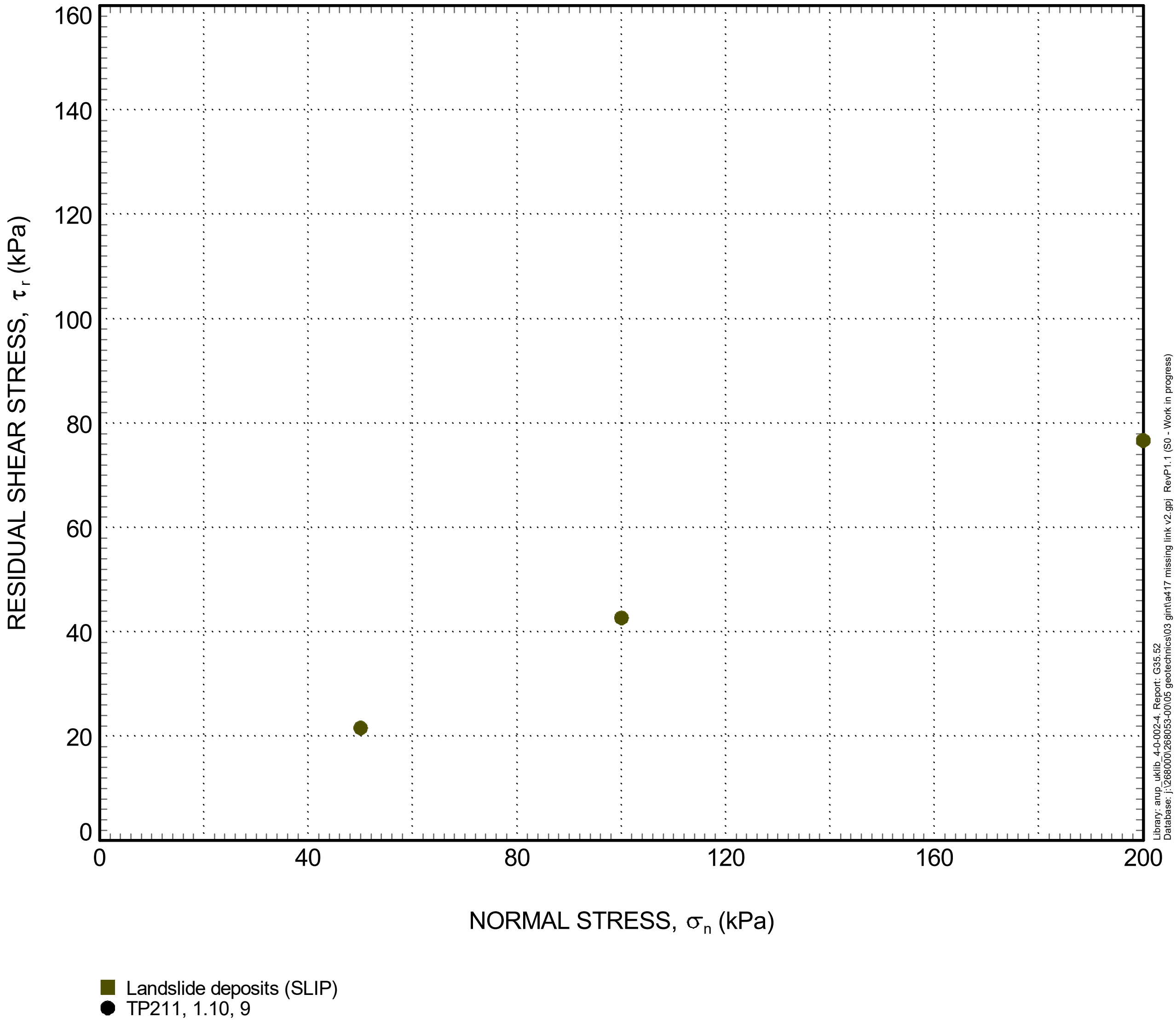
FIGURE: F4B.05



A417 - MISSING LINK
SHEAR BOX TESTS

MASS MOVEMENT DEPOSITS - SHAB HILL

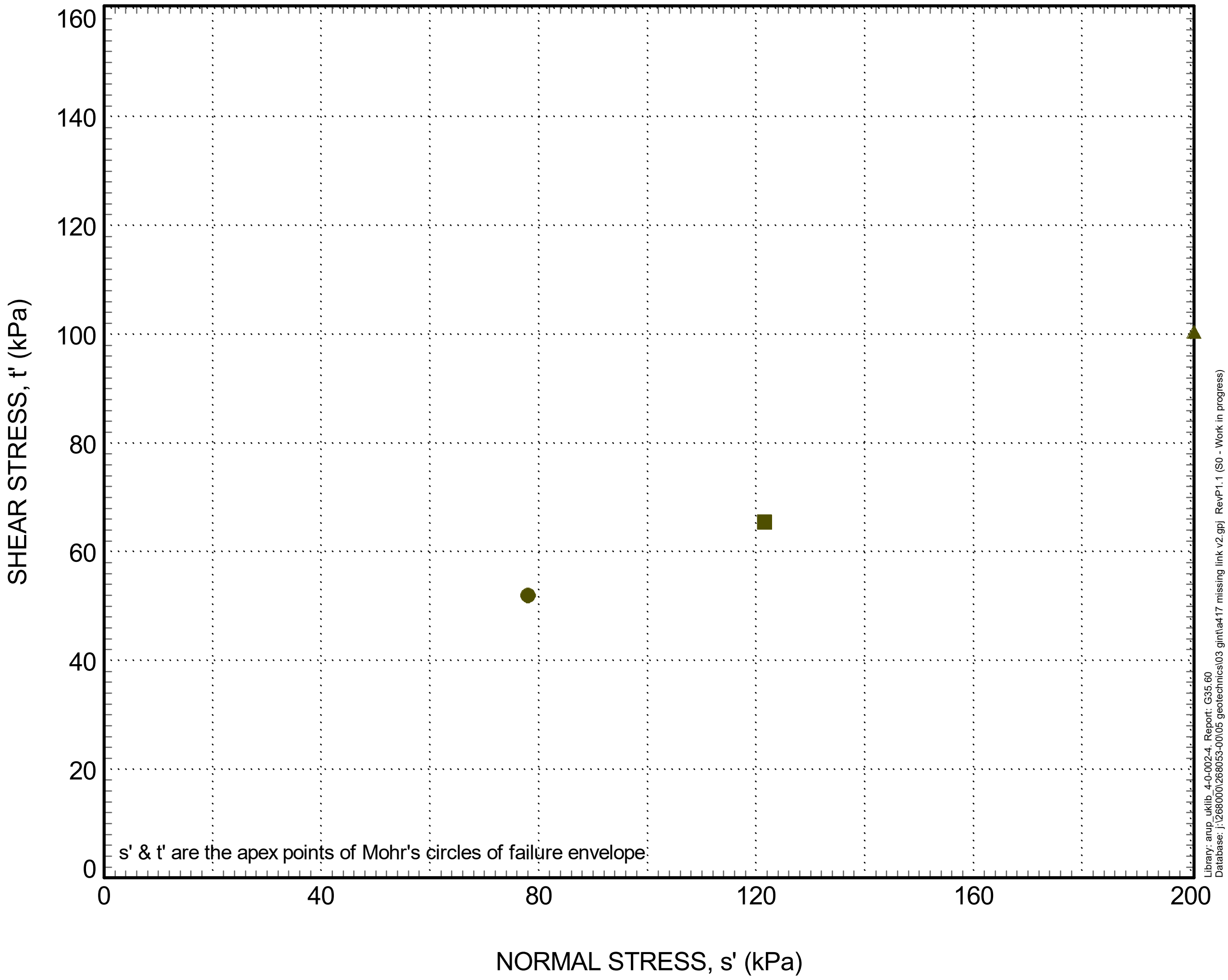
FIGURE: F4B.06



A417 - MISSING LINK
SHEAR BOX TESTS

MASS MOVEMENT DEPOSITS - SHAB HILL

FIGURE: F4B.07

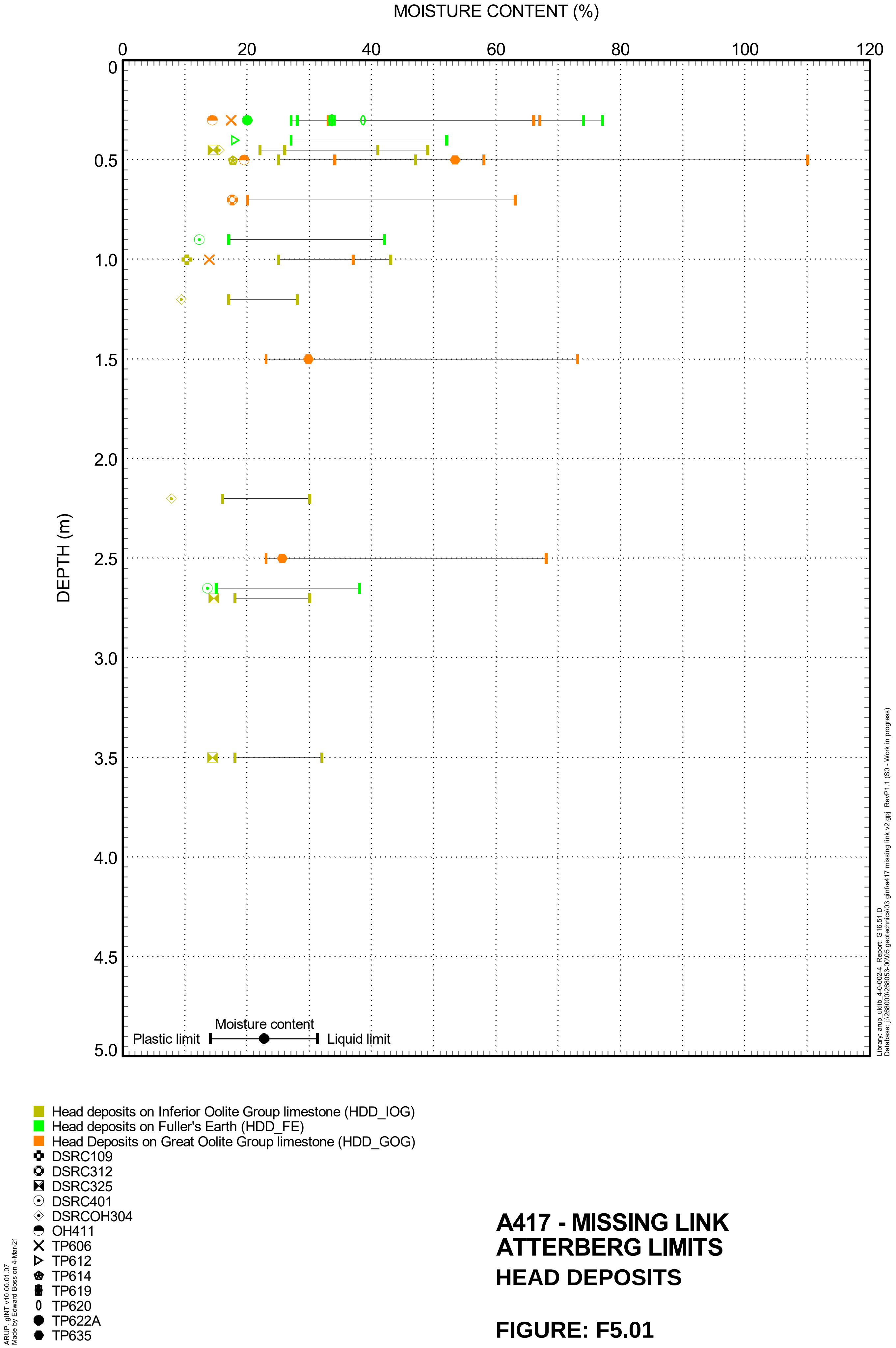


Landslide deposits (SLIP)
TP211, 1.10, 9
TP211, 1.10, 9
TP211, 1.10, 9

A417 - MISSING LINK
TRIAXIAL T' V S'

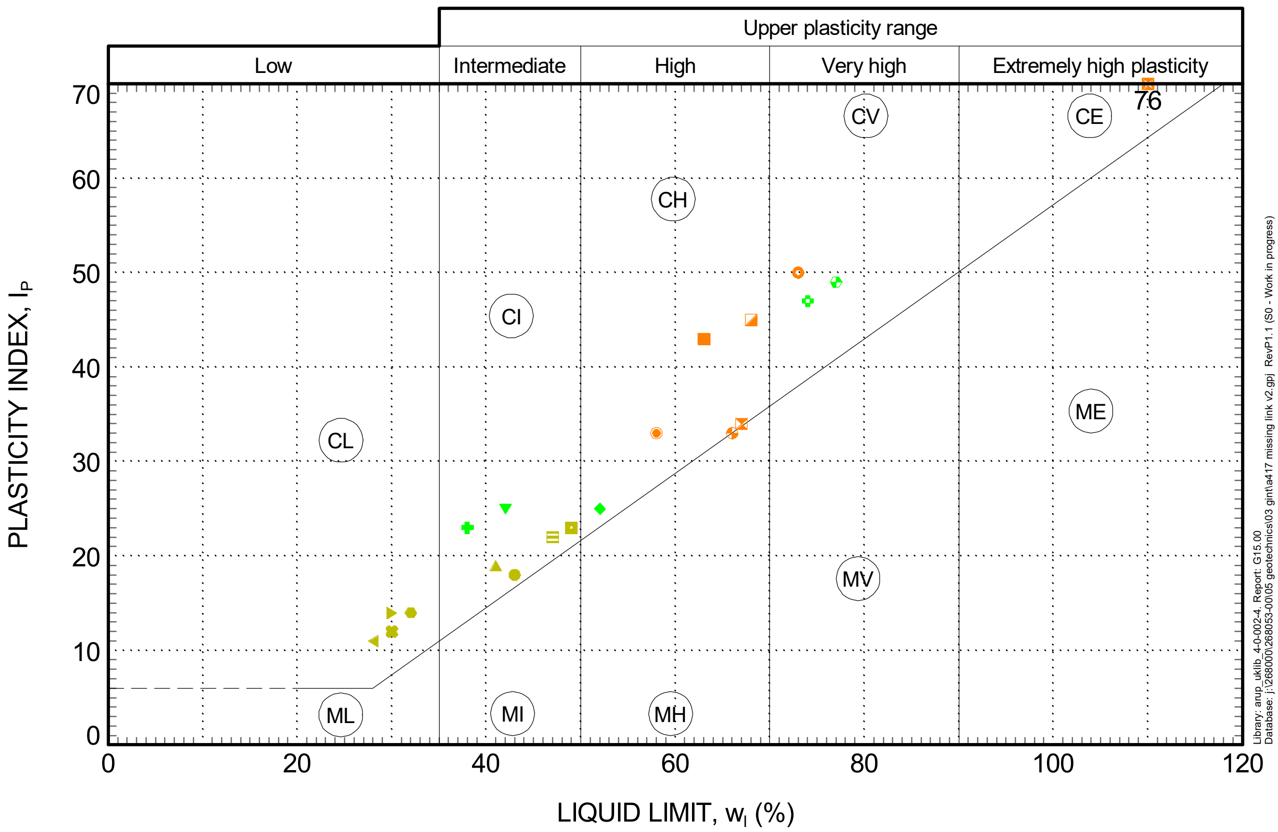
MASS MOVEMENT DEPOSITS - SHAB HILL
FIGURE: F4B.08

F.5 Head Deposits



A417 - MISSING LINK
ATTERBERG LIMITS
HEAD DEPOSITS

FIGURE: F5.01



Head deposits on Inferior Oolite Group limestone (HDD_IOG)
Head deposits on Fuller's Earth (HDD_FE)
Head Deposits on Great Oolite Group limestone (HDD_GOG)
DSRC109, 1.00, 2
DSRC312, 0.70, 6
DSRC325, 0.45, 6
DSRC325, 2.70, 13
DSRC325, 3.50, 16
DSRC401, 0.90, 3
DSRC401, 2.65, 5
DSRCOH304, 0.45, 6
DSRCOH304, 1.20, 9
DSRCOH304, 2.20, 12
OH411, 0.30, 4
OH411, 0.50, 6
TP606, 0.30, 4
TP612, 0.40, 3
TP614, 0.50, 3
TP619, 0.30, 1
TP620, 0.30, 1
TP635, 0.50, 6
TP635, 1.50, 10
TP635, 2.50, 12

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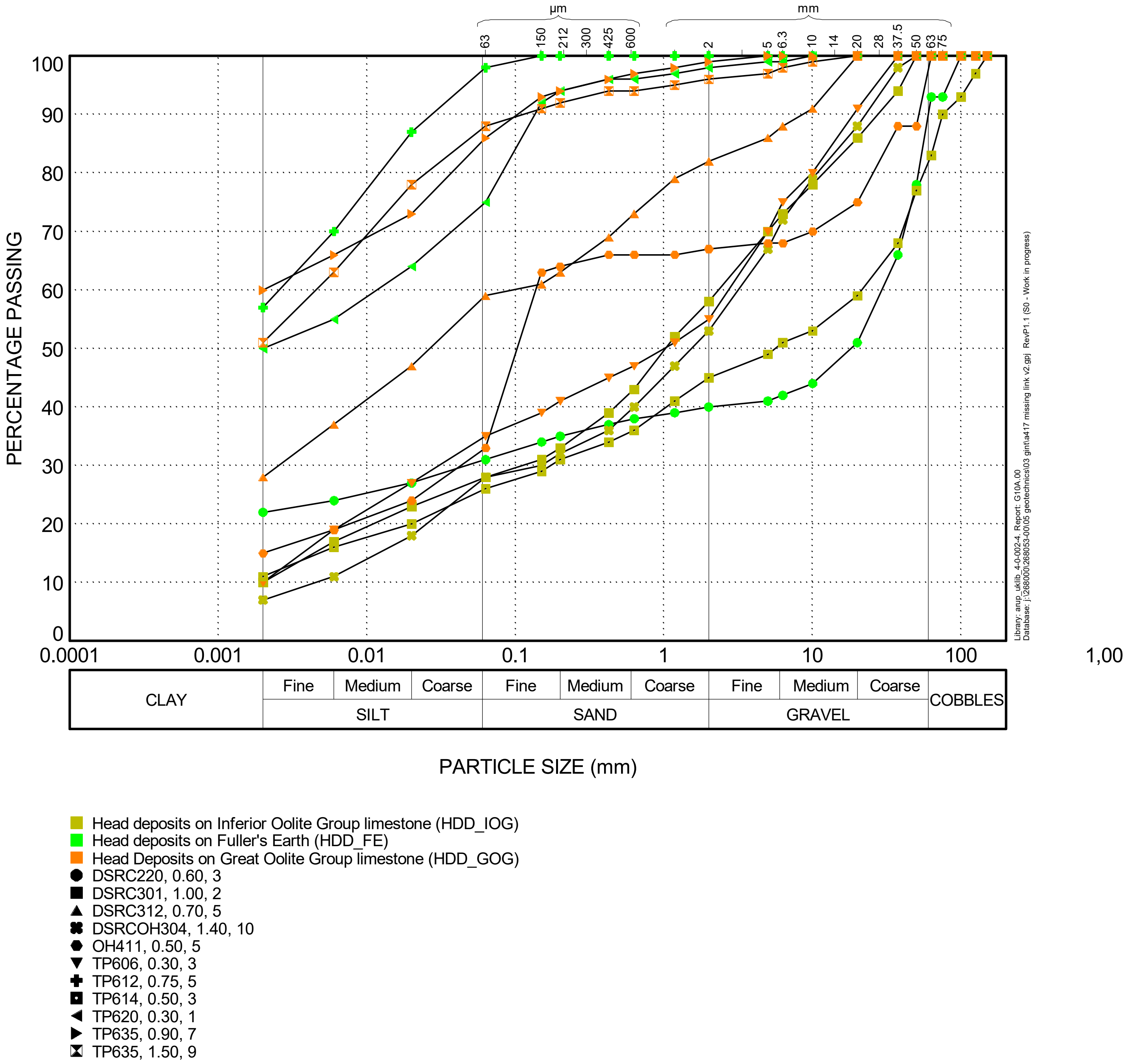
A417 - MISSING LINK
PLASTICITY CHART
HEAD DEPOSITS

FIGURE: F5.02

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



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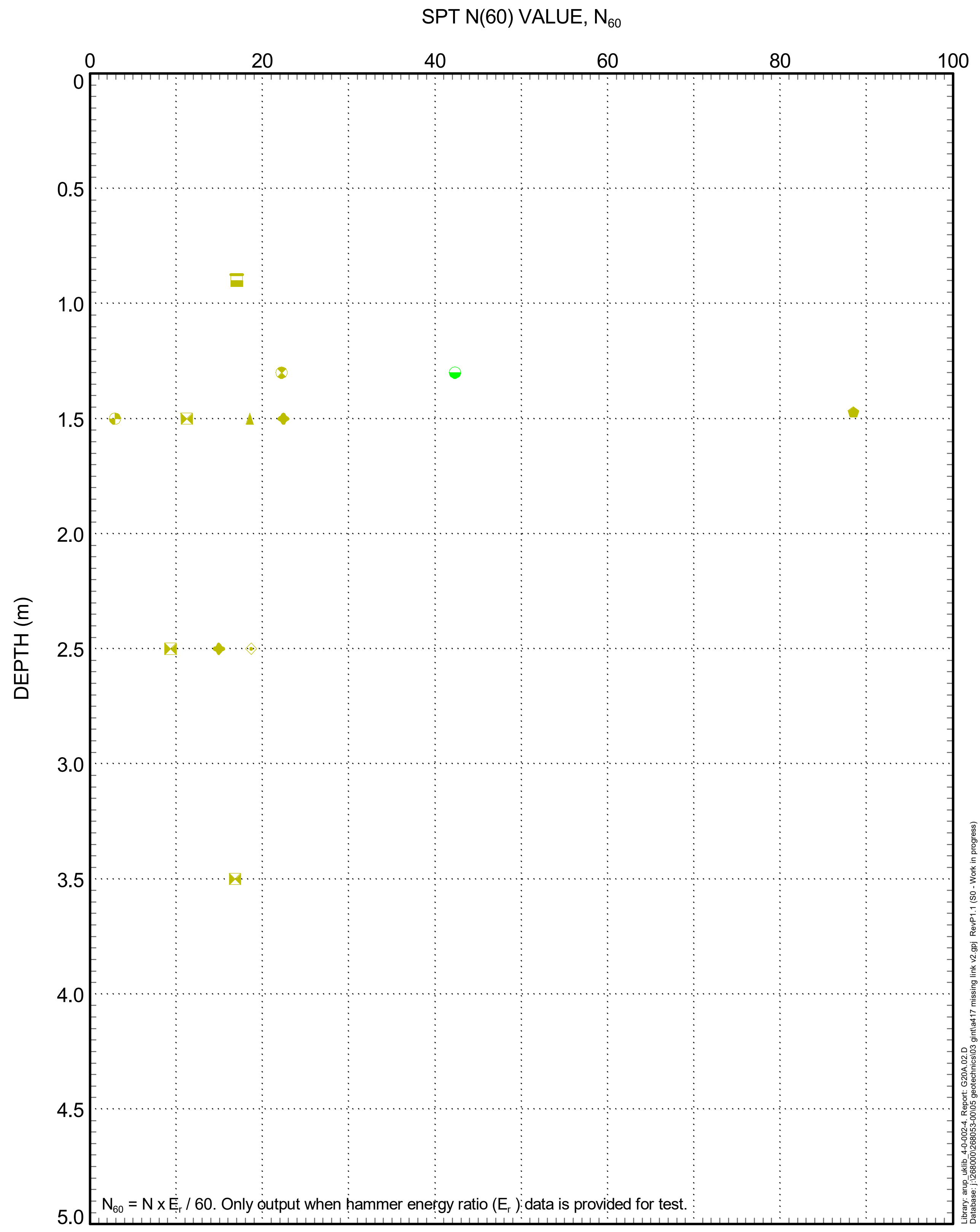
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
HEAD DEPOSITS

FIGURE: F5.03

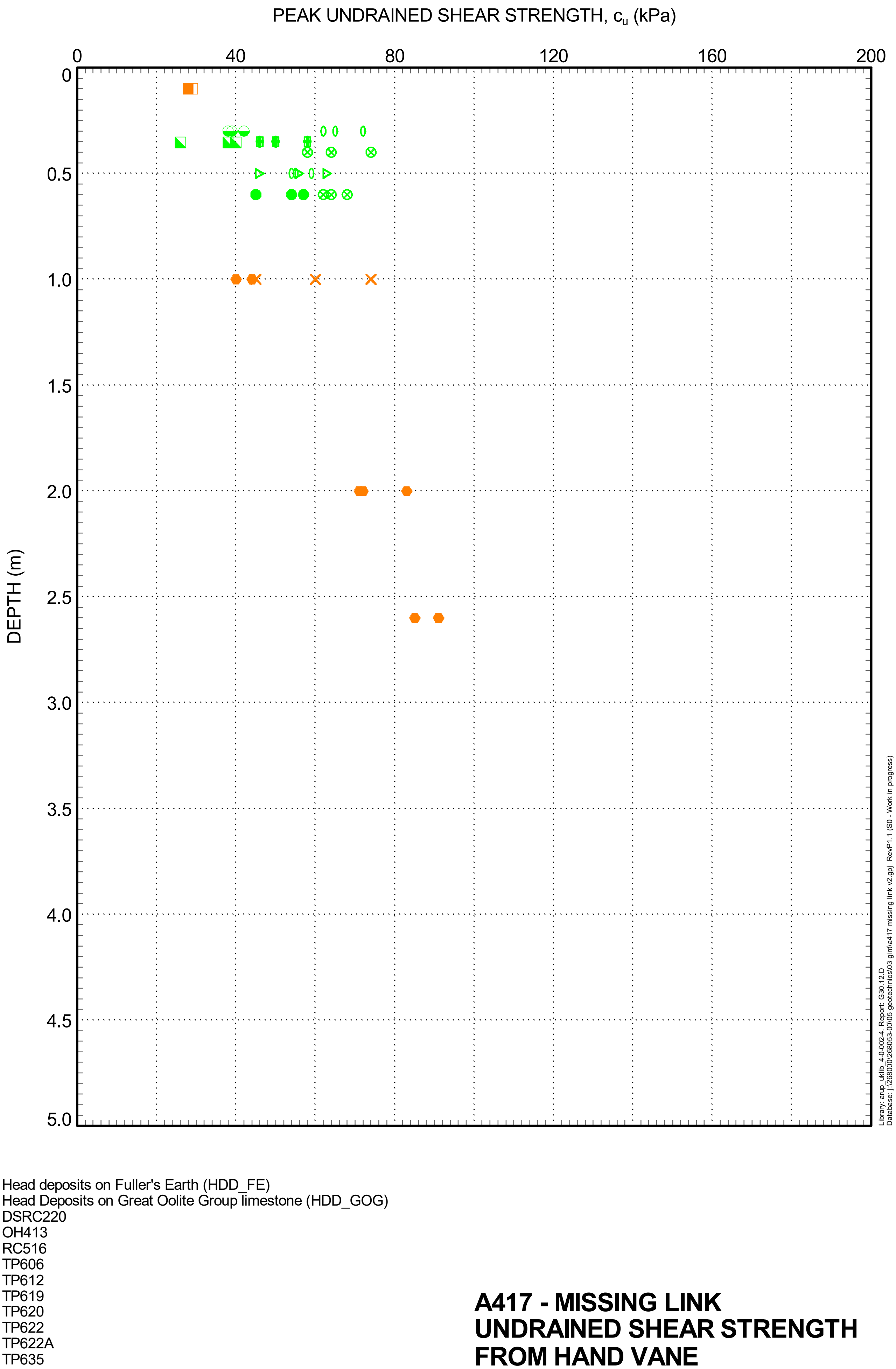


Head deposits on Inferior Oolite Group limestone (HDD_IOG)
Head deposits on Fuller's Earth (HDD_FE)
DSRC220
DSRC301
DSRC319
DSRC325
DSRC404
DSRC406
DSRC418
DSRC419
DSRCOH304

A417 - MISSING LINK
STANDARD PENETRATION TESTS
HEAD DEPOSITS

FIGURE: F5.04

Library: arup_uklib_4-0-002-4, Report: G20A 02.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)
ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

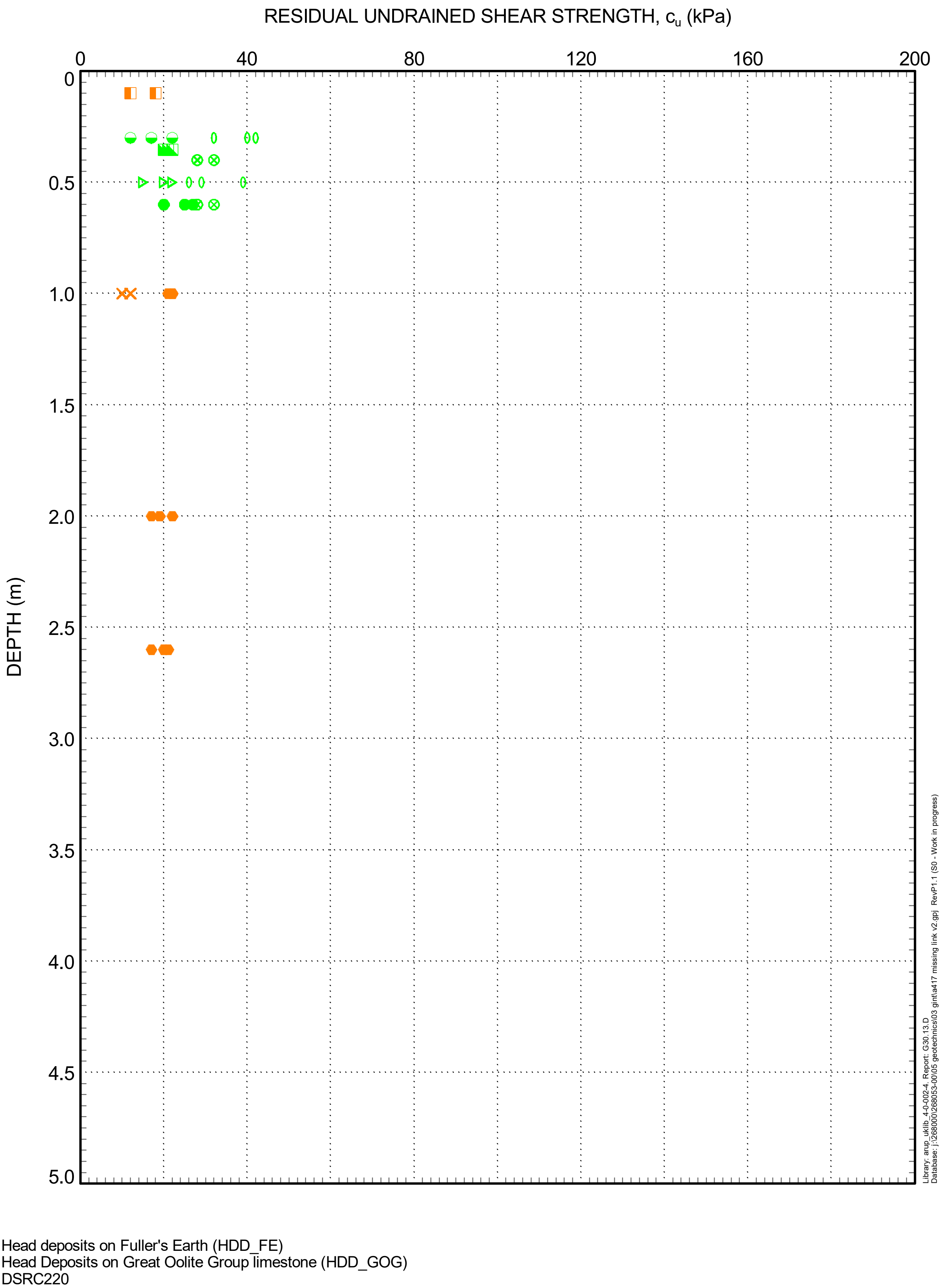


ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM HAND VANE

HEAD DEPOSITS

FIGURE: F5.05



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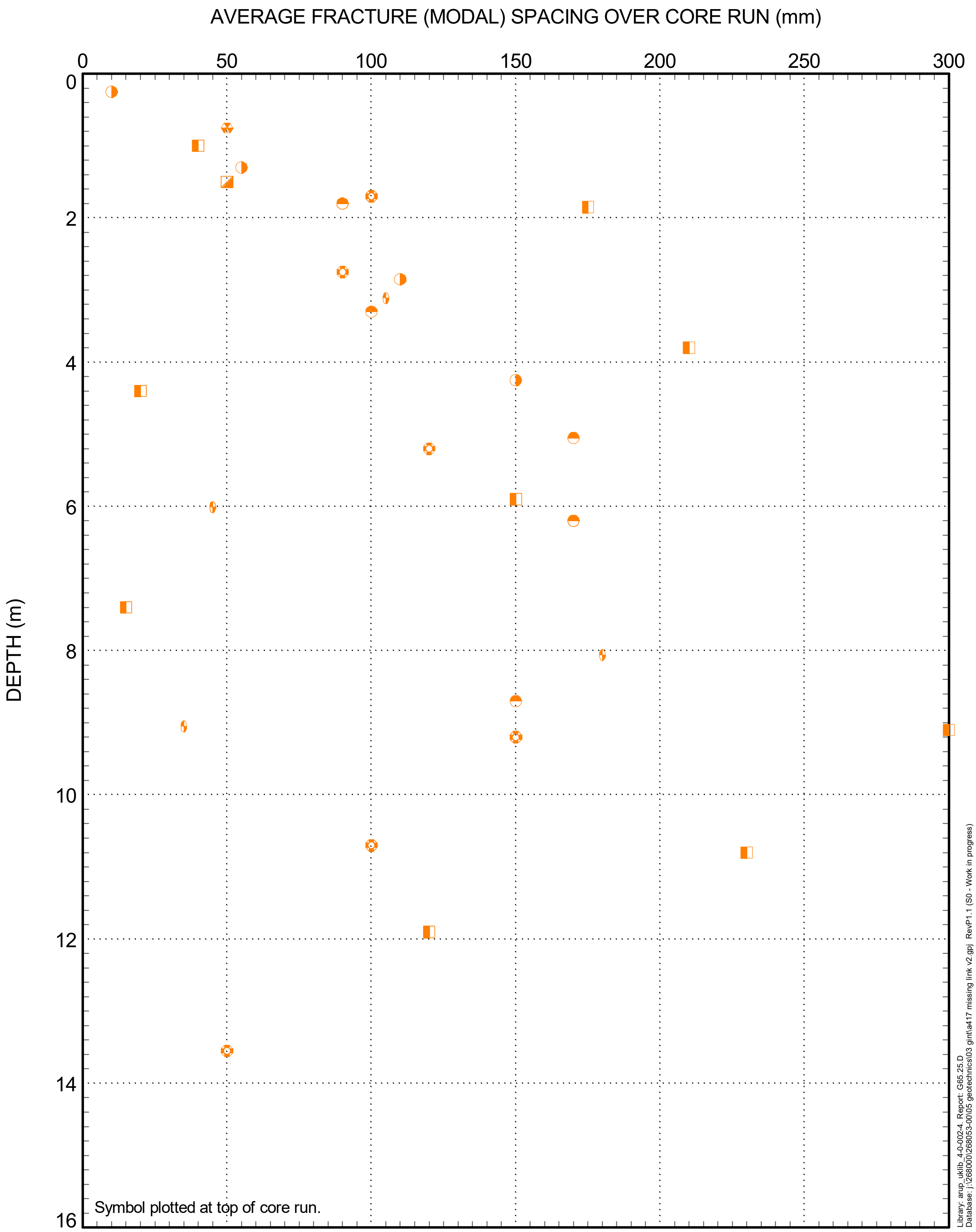
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM HAND VANE
HEAD DEPOSITS

FIGURE: F5.06

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

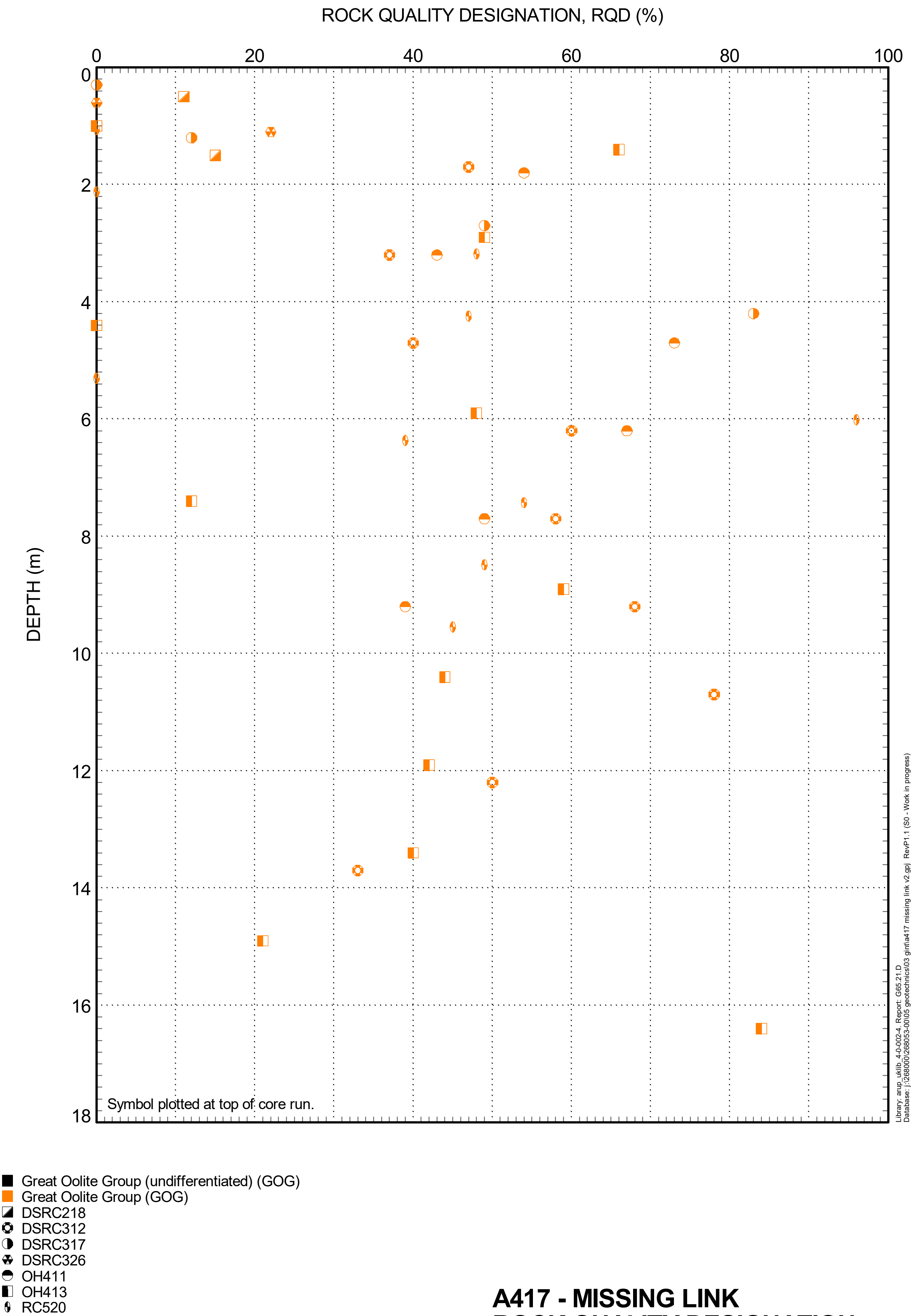
F.6 Great Oolite Group – limestone



- Great Oolite Group (undifferentiated) (GOG)
- Great Oolite Group (GOG)
- DSRC218
- DSRC312
- DSRC317
- DSRC326
- OH411
- OH413
- RC520

A417 - MISSING LINK
FRACTURE SPACING
GREAT OOLITE GROUP

FIGURE: F6.01

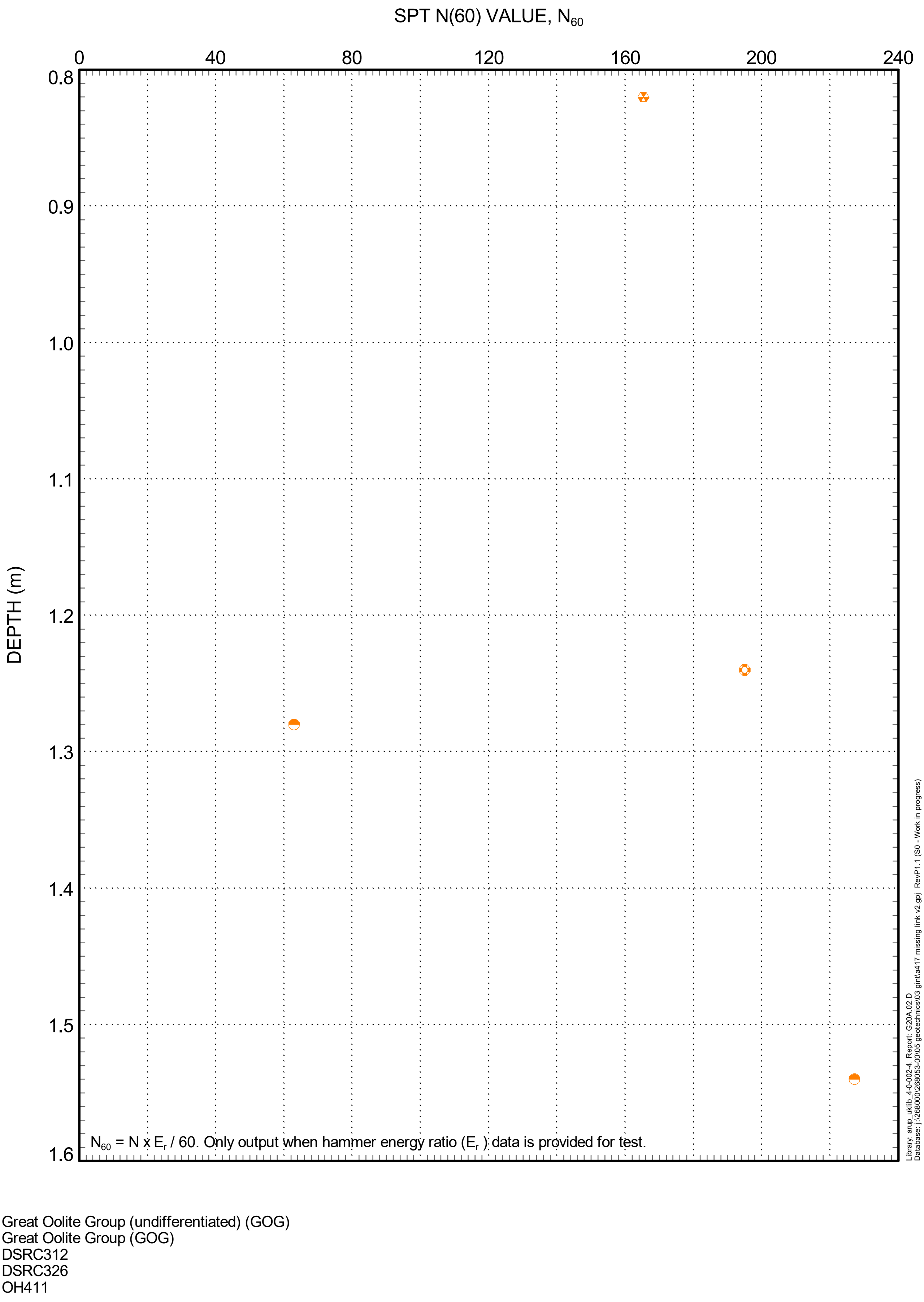


Library: arup_uklib_4-0-002-4, Report: G65.21.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
ROCK QUALITY DESIGNATION
GREAT OOLITE GROUP

FIGURE: F6.02

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



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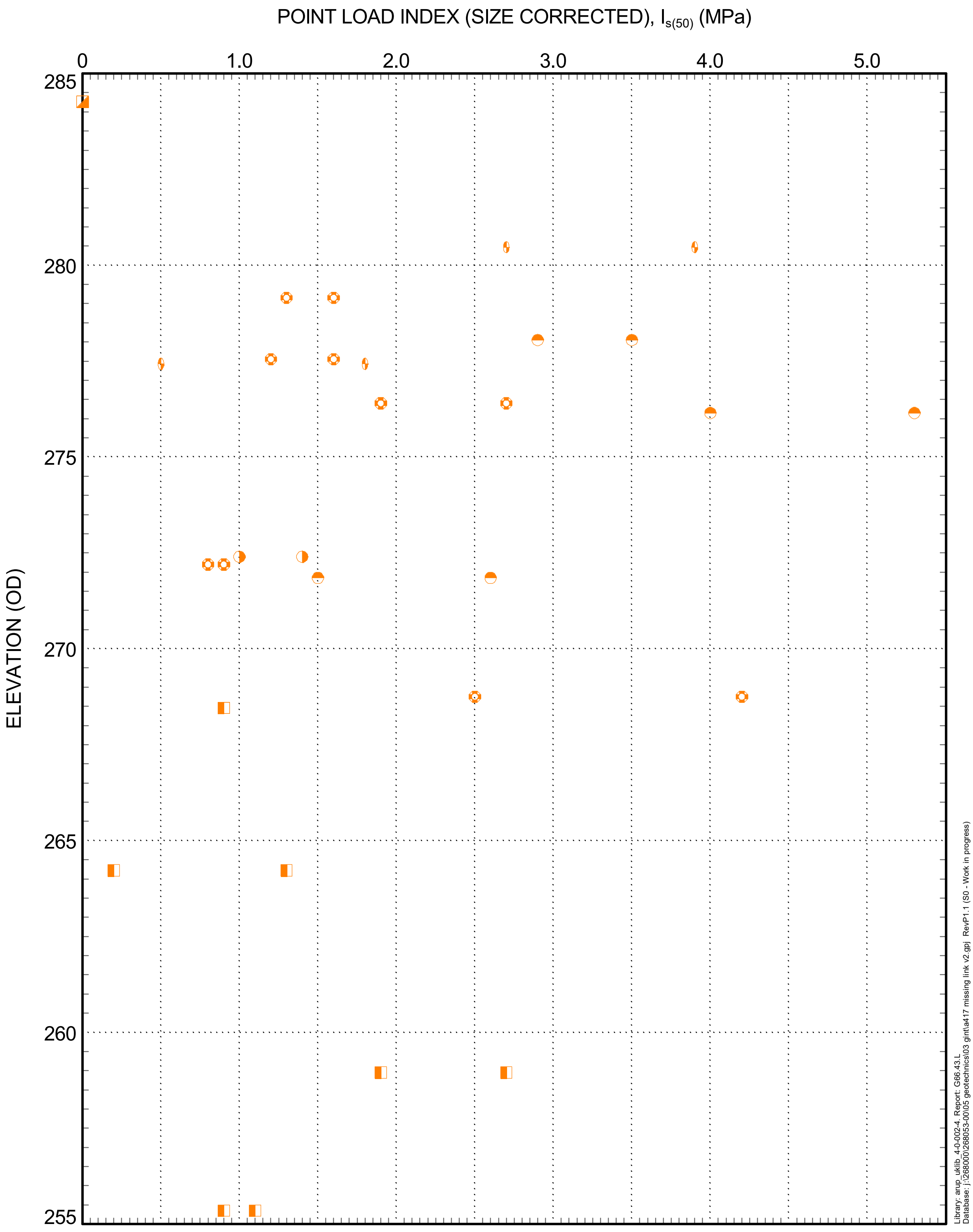
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
STANDARD PENETRATION TESTS
GREAT OOLITE GROUP

FIGURE: F6.03

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



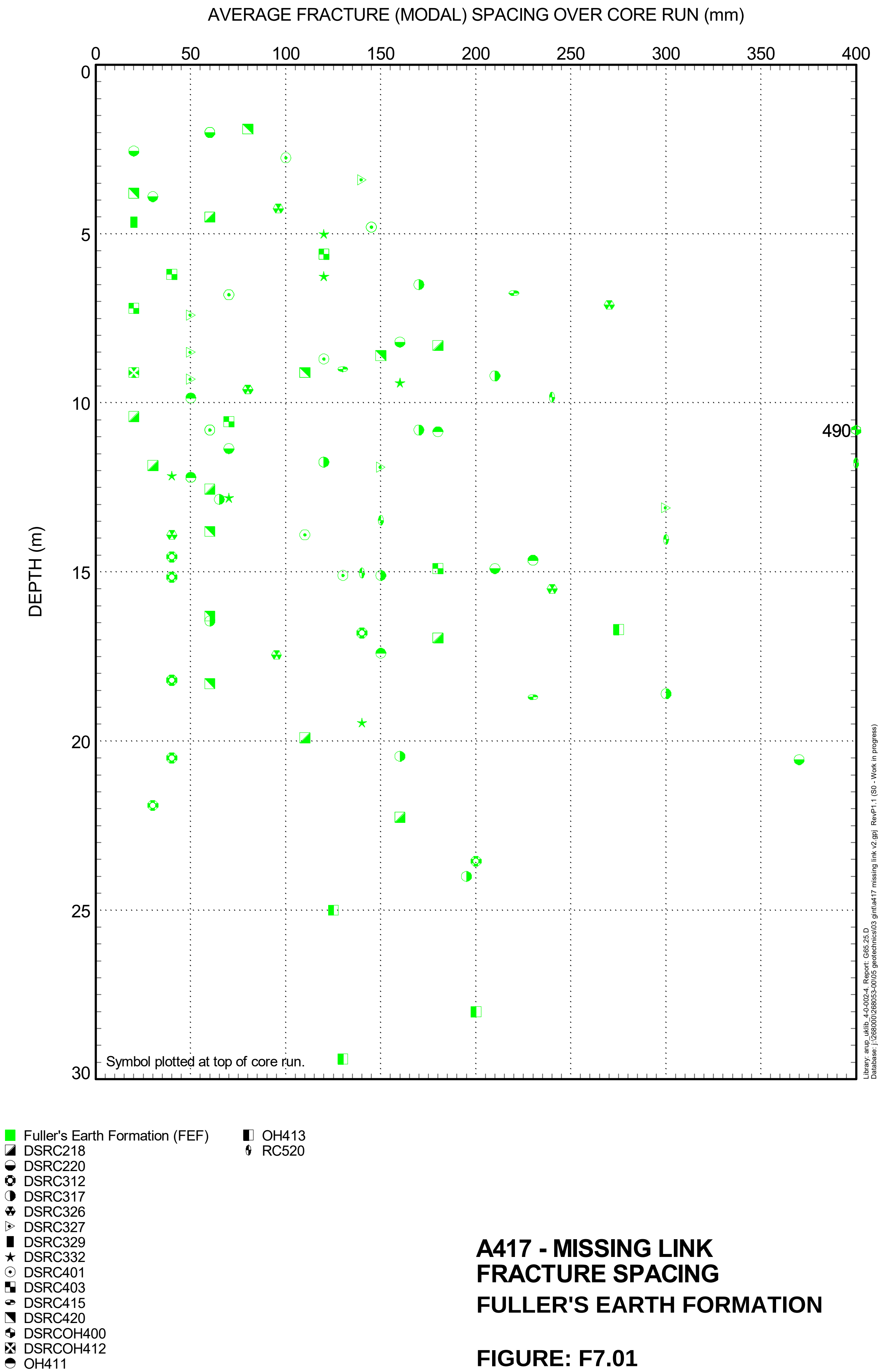
Great Oolite Group (undifferentiated) (GOG)
Great Oolite Group (GOG)
DSRC218
DSRC312
DSRC317
OH411
OH413
RC520

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
POINT LOAD INDEX (SIZE CORRECTED)
GREAT OOLITE GROUP

FIGURE: F6.04

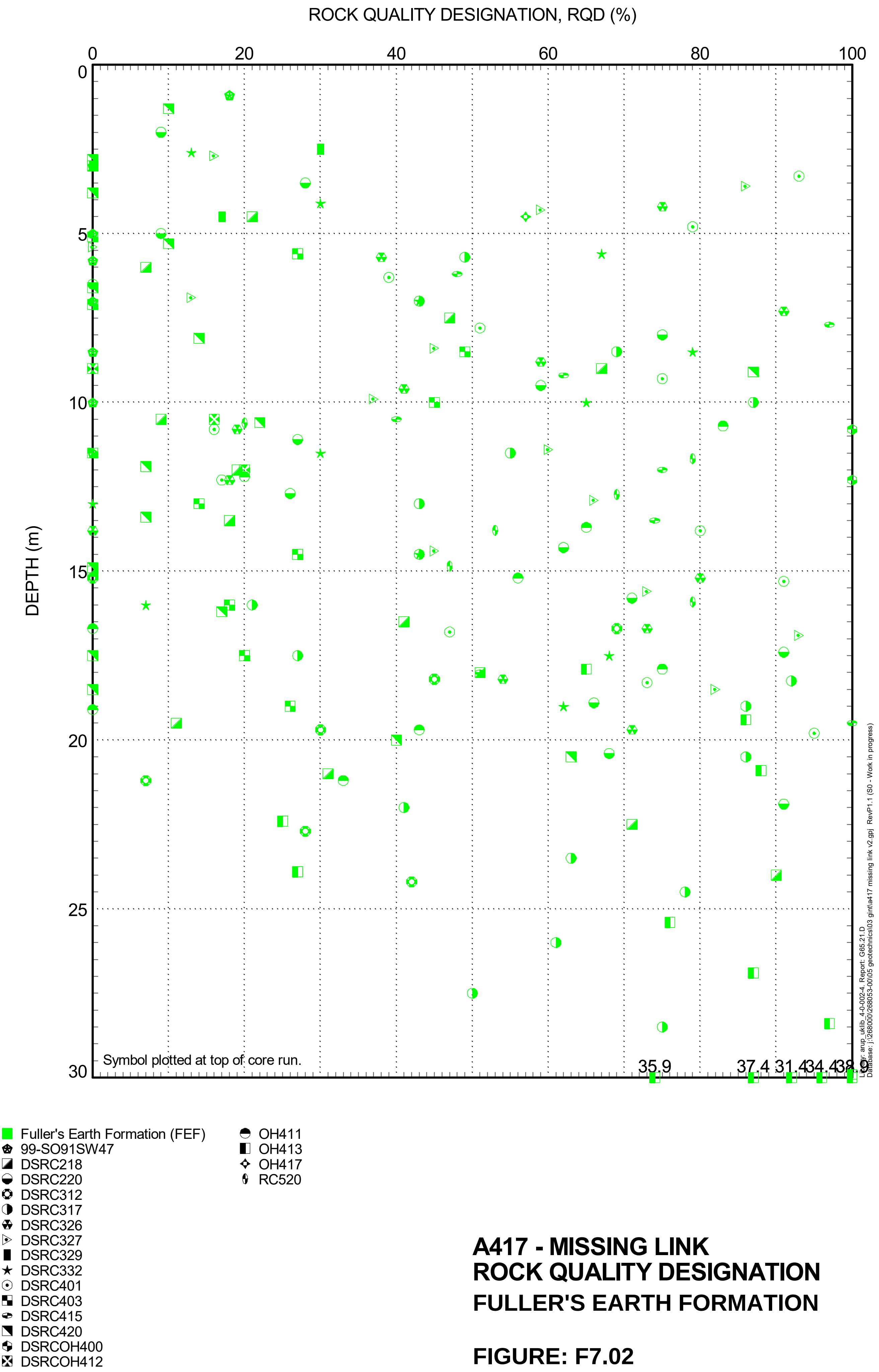
F.7 Great Oolite Group – Fuller's Earth Formation



ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
FRACTURE SPACING
FULLER'S EARTH FORMATION

FIGURE: F7.01

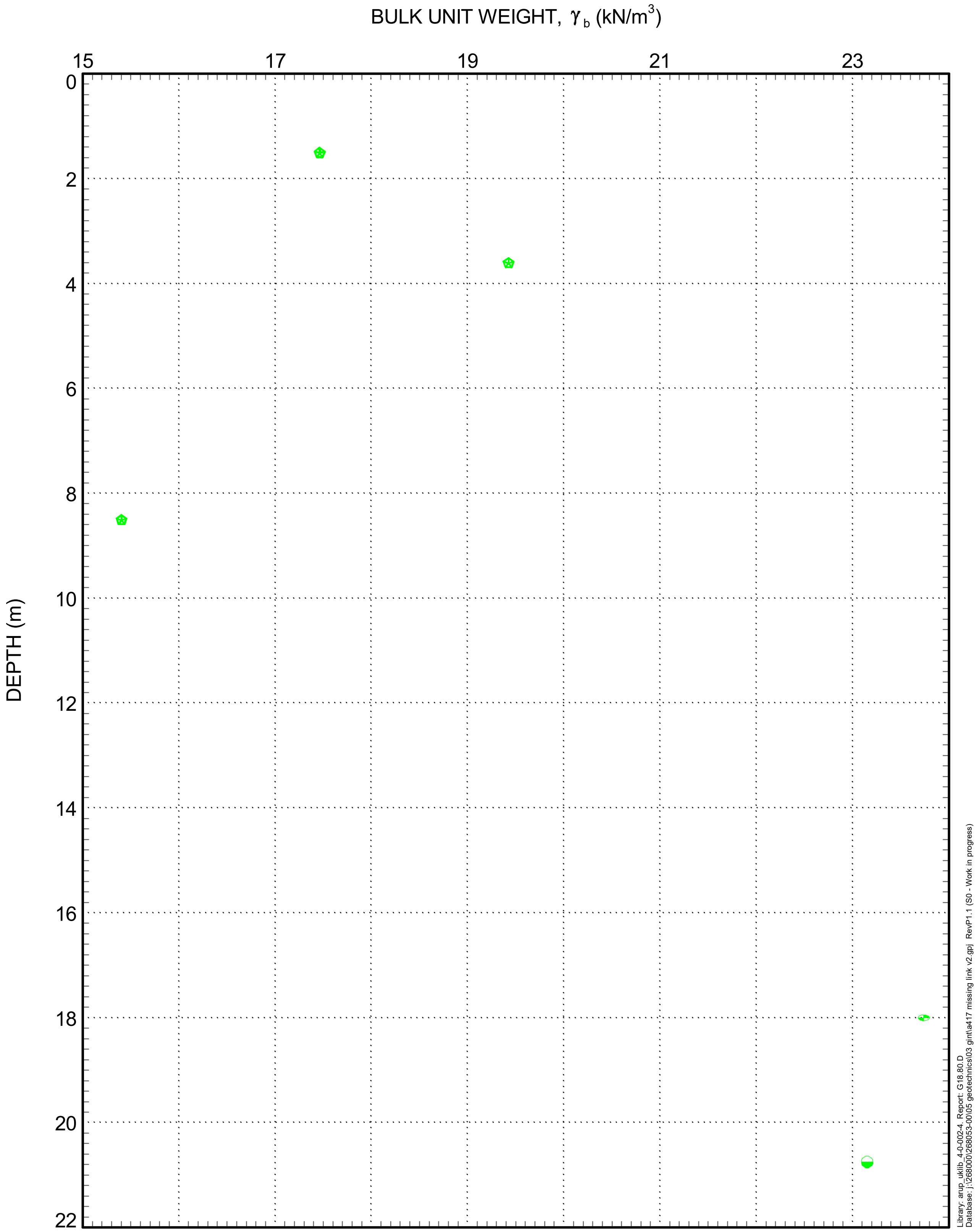


Library: arup_uklib_4-0-002-4. Report: G65.21.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ROCK QUALITY DESIGNATION
FULLER'S EARTH FORMATION

FIGURE: F7.02

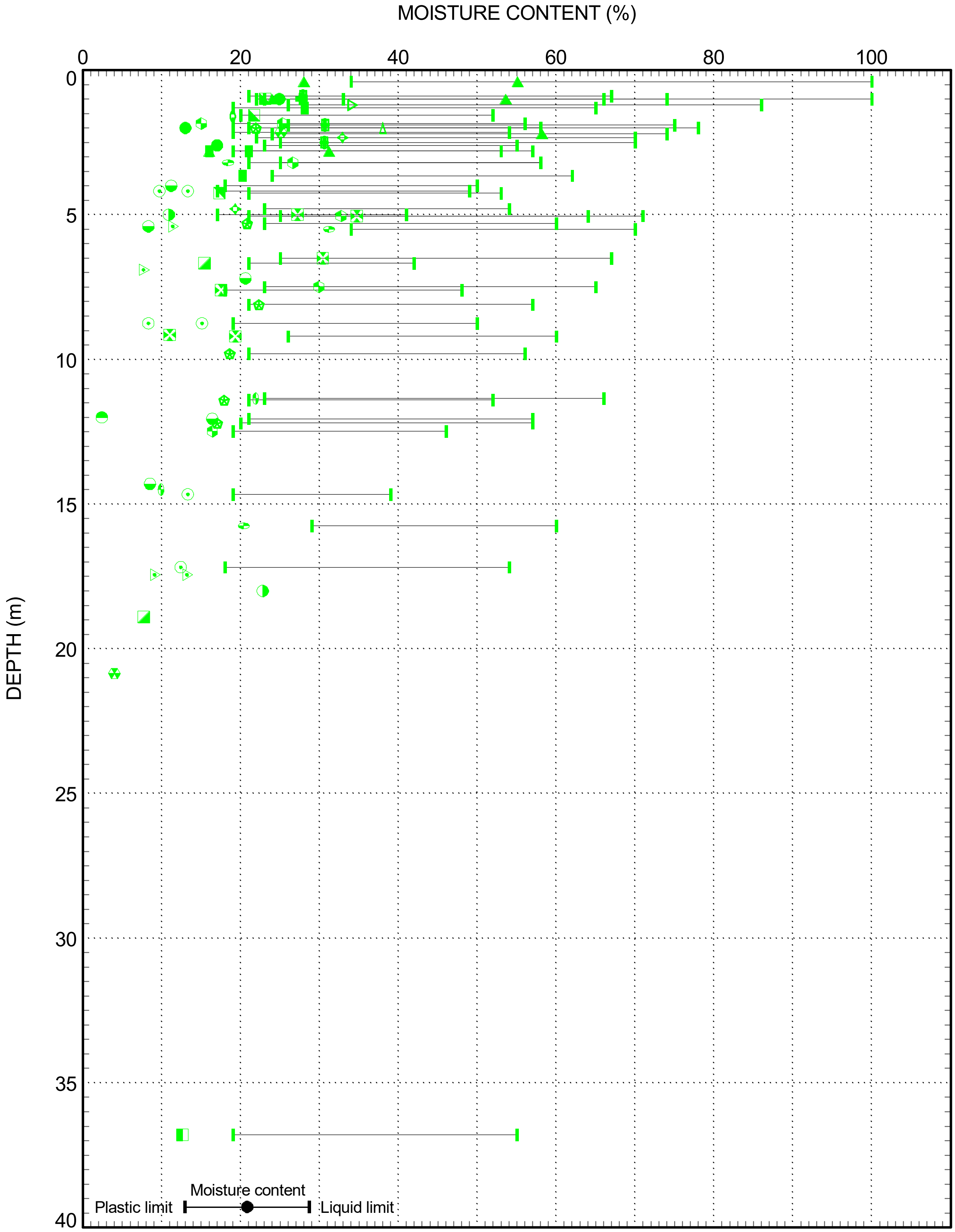


Fuller's Earth Formation (FEF)
99-SO91SW47
DSRC220
DSRC415

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
BULK UNIT WEIGHT
FULLER'S EARTH FORMATION

FIGURE: F7.03

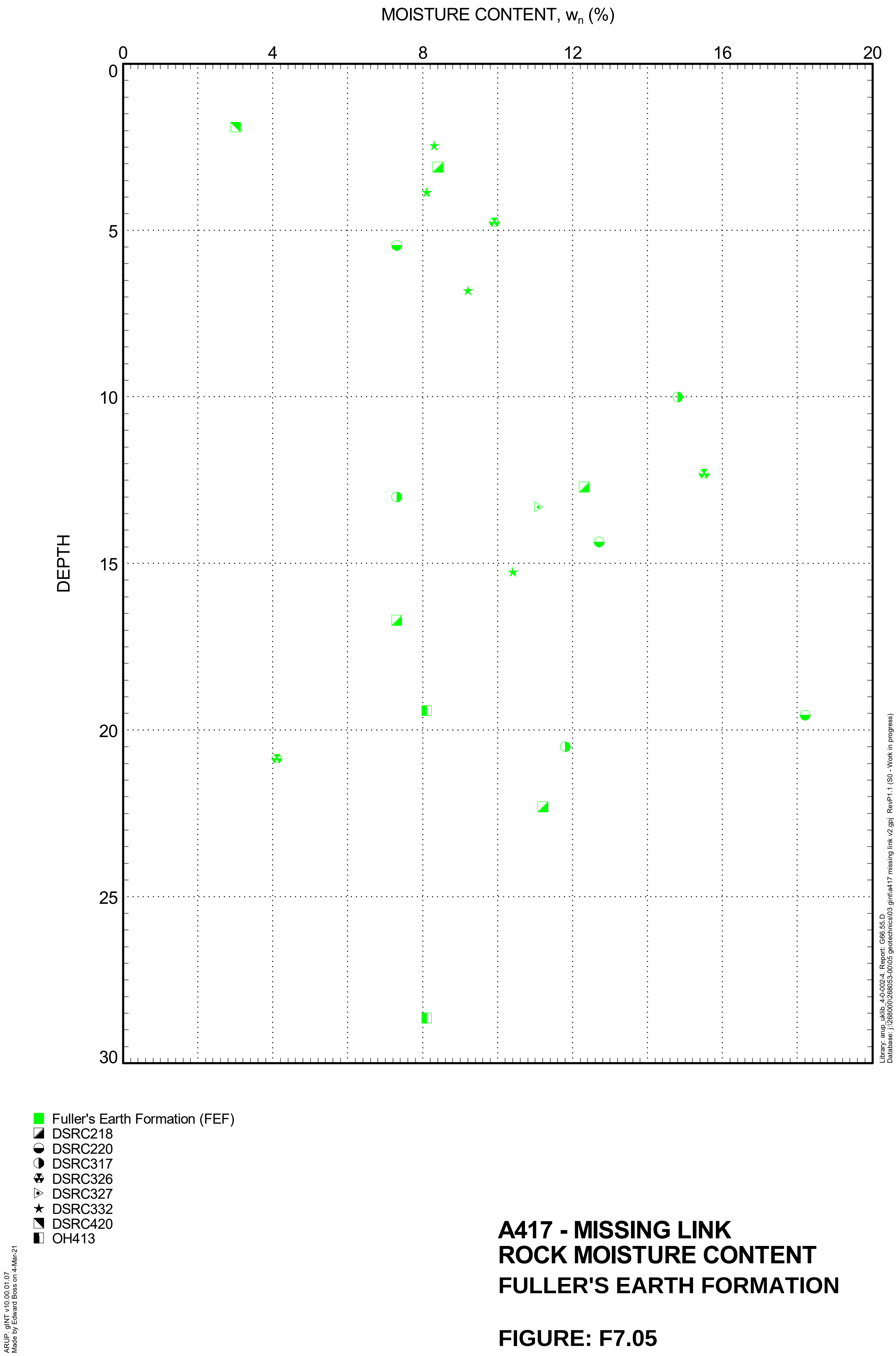


- Fuller's Earth Formation (FEF)
- 99-SO91SW47
- DSRC218
- DSRC220
- DSRC317
- DSRC326
- DSRC327
- DSRC329
- DSRC401
- DSRC415
- DSRC420
- DSRCOH400
- DSRCOH412
- OH411
- OH413
- OH417
- RC516
- RC520
- TP603
- TP612
- TP619
- TP620
- TP622A
- TP628
- TP637

A417 - MISSING LINK
ATTERBERG LIMITS
FULLER'S EARTH FORMATION

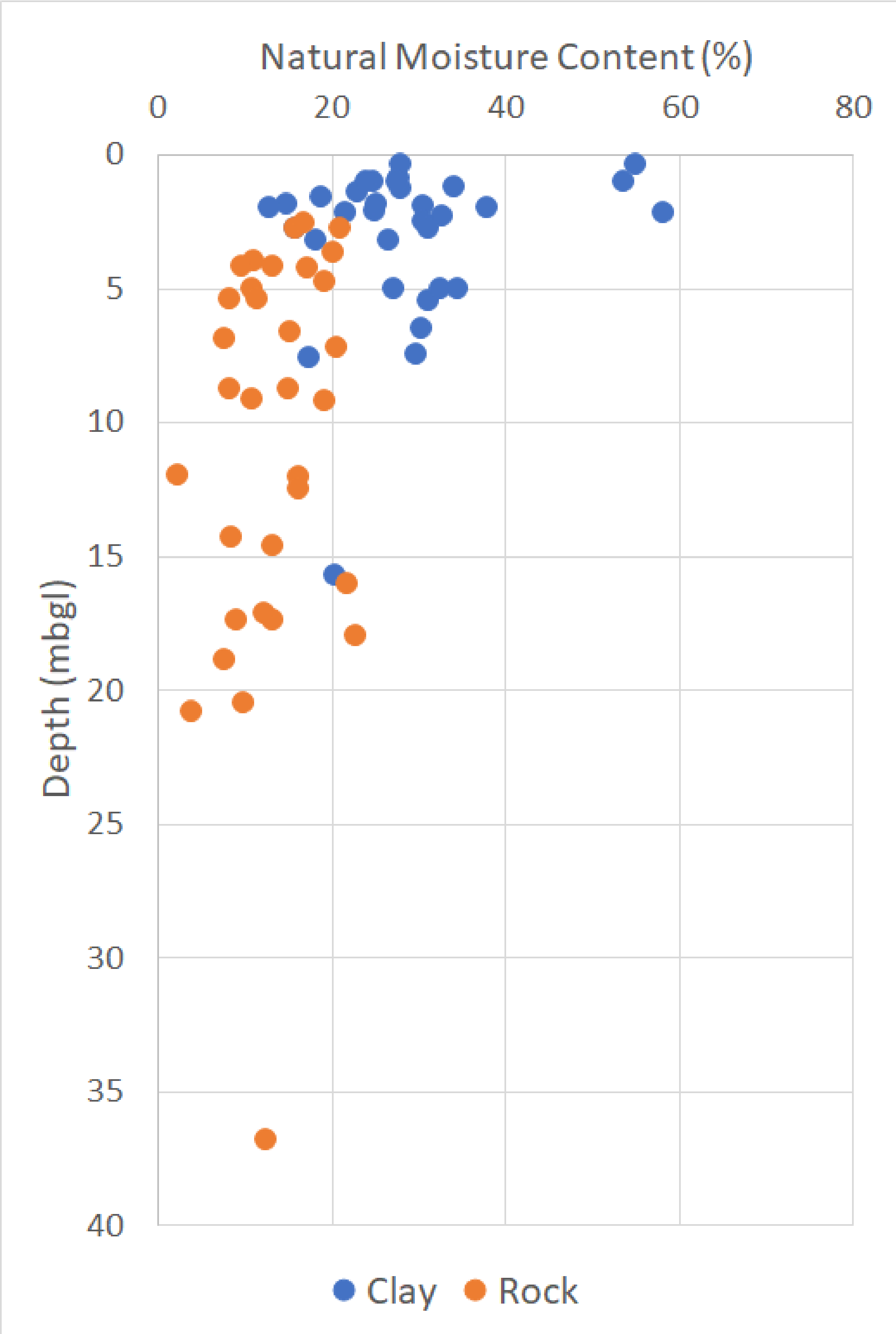
FIGURE: F7.04

Library: arup_uklib_4-0-002-4, Report: G16.51.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)
ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

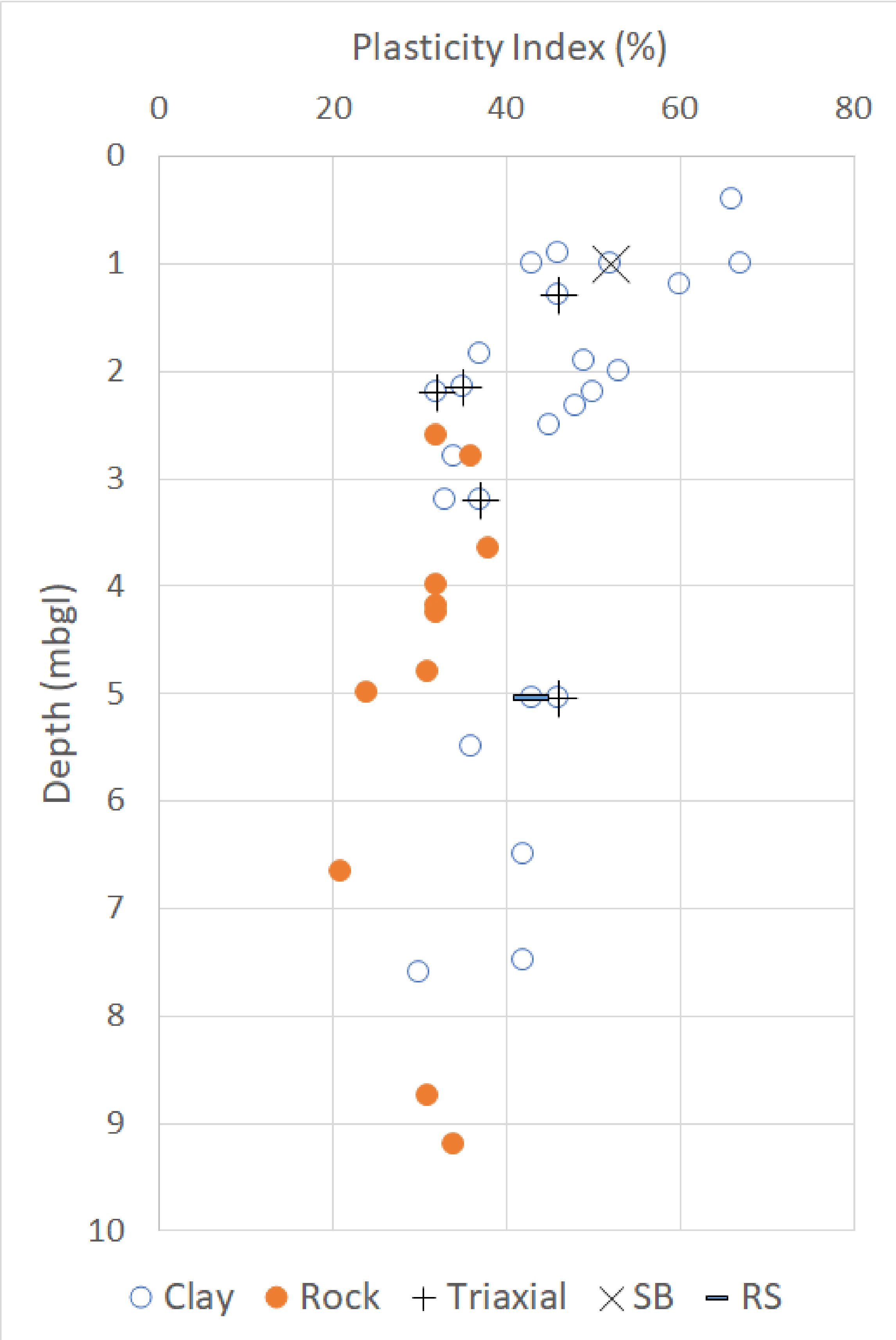


A417 - MISSING LINK
ROCK MOISTURE CONTENT
FULLER'S EARTH FORMATION

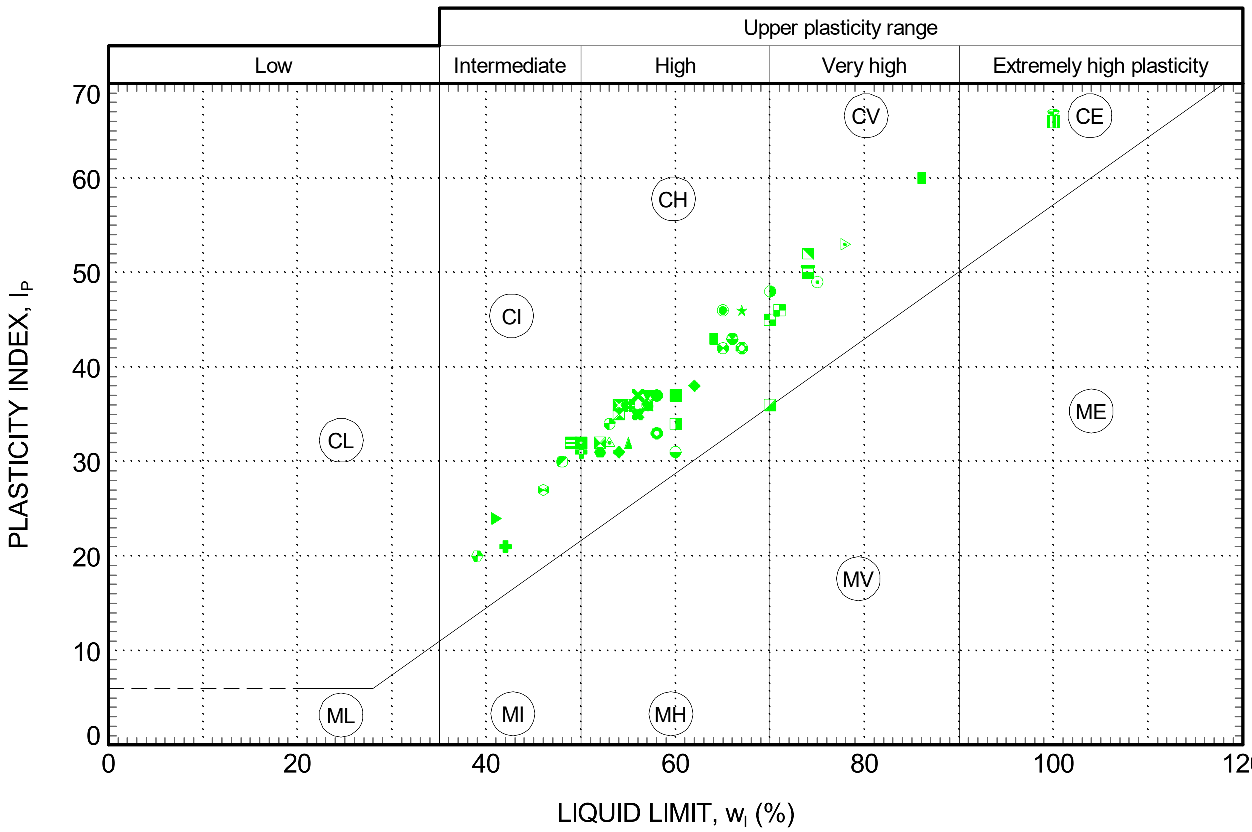
FIGURE: F7.05



FULLER'S EARTH FORMATION
A417 - MISSING LINK
NATURAL MOISTURE CONTENT
FIGURE: F7.06



FULLER'S EARTH FORMATION
A417 - MISSING LINK
PLASTICITY INDEX
FIGURE: F7.07



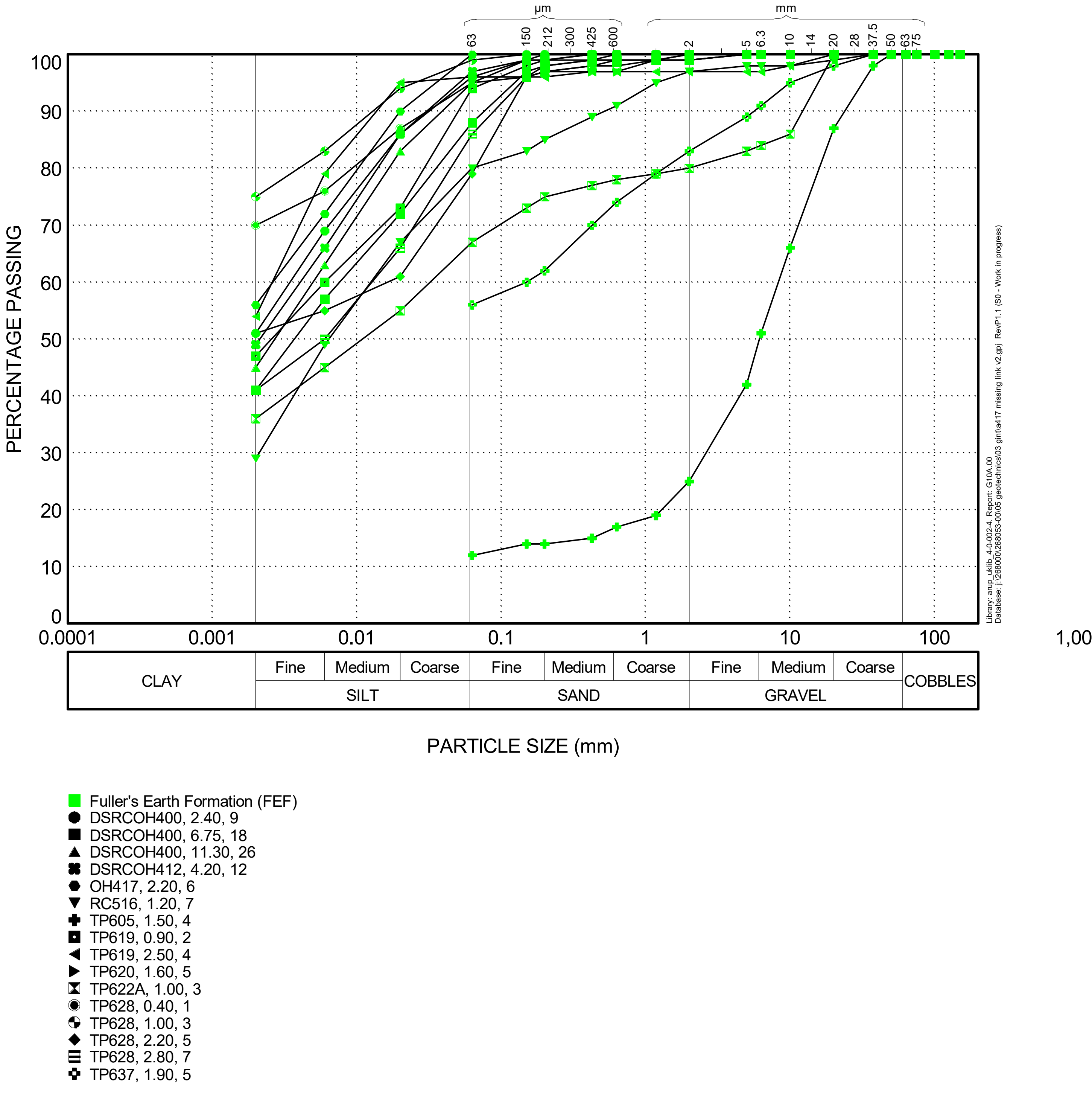
- Fuller's Earth Formation (FEF)
- 99-SO91SW47, 2.00, 6
- 99-SO91SW47, 5.30, 9
- 99-SO91SW47, 8.10, 11
- 99-SO91SW47, 9.80, 12
- 99-SO91SW47, 11.40, 13
- 99-SO91SW47, 12.20, 14
- DSRC218, 6.67, 12
- DSRC220, 4.00, 9
- DSRC220, 12.05, 19
- DSRC317, 5.00, 9
- DSRC326, 2.15, 6
- DSRC329, 1.30, 7
- DSRC329, 2.80, 9
- DSRC329, 3.65, 11
- DSRC401, 4.18, 7
- DSRC401, 8.75, 13
- DSRC401, 14.66, 20
- DSRC401, 17.18, 23
- DSRC415, 3.20, 8
- DSRC415, 5.50, 11
- DSRC415, 15.75, 19
- DSRC420, 4.25, 10
- DSRCOH400, 1.85, 7
- DSRCOH400, 3.20, 10
- DSRCOH400, 5.04, 14
- DSRCOH400, 7.49, 19
- DSRCOH400, 12.48, 28
- DSRCOH412, 5.05, 14
- DSRCOH412, 6.50, 20
- DSRCOH412, 7.60, 23
- DSRCOH412, 9.20, 27
- OH413, 36.80, 48
- OH417, 2.33, 7
- OH417, 4.80, 10
- RC516, 2.20, 9
- RC520, 16.05, 18
- TP603, 2.00, 4
- TP612, 1.20, 7
- TP619, 0.90, 2
- TP619, 1.90, 3
- TP619, 2.50, 4
- TP622A, 1.00, 3
- TP622A, 2.60, 7
- TP628, 0.40, 1
- TP628, 1.00, 3
- TP628, 2.20, 5
- TP628, 2.80, 7
- TP637, 1.00, 4

Library: arup_uklib_4-0-002-4. Report: G15.00
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
PLASTICITY CHART
FULLER'S EARTH FORMATION

FIGURE: F7.08

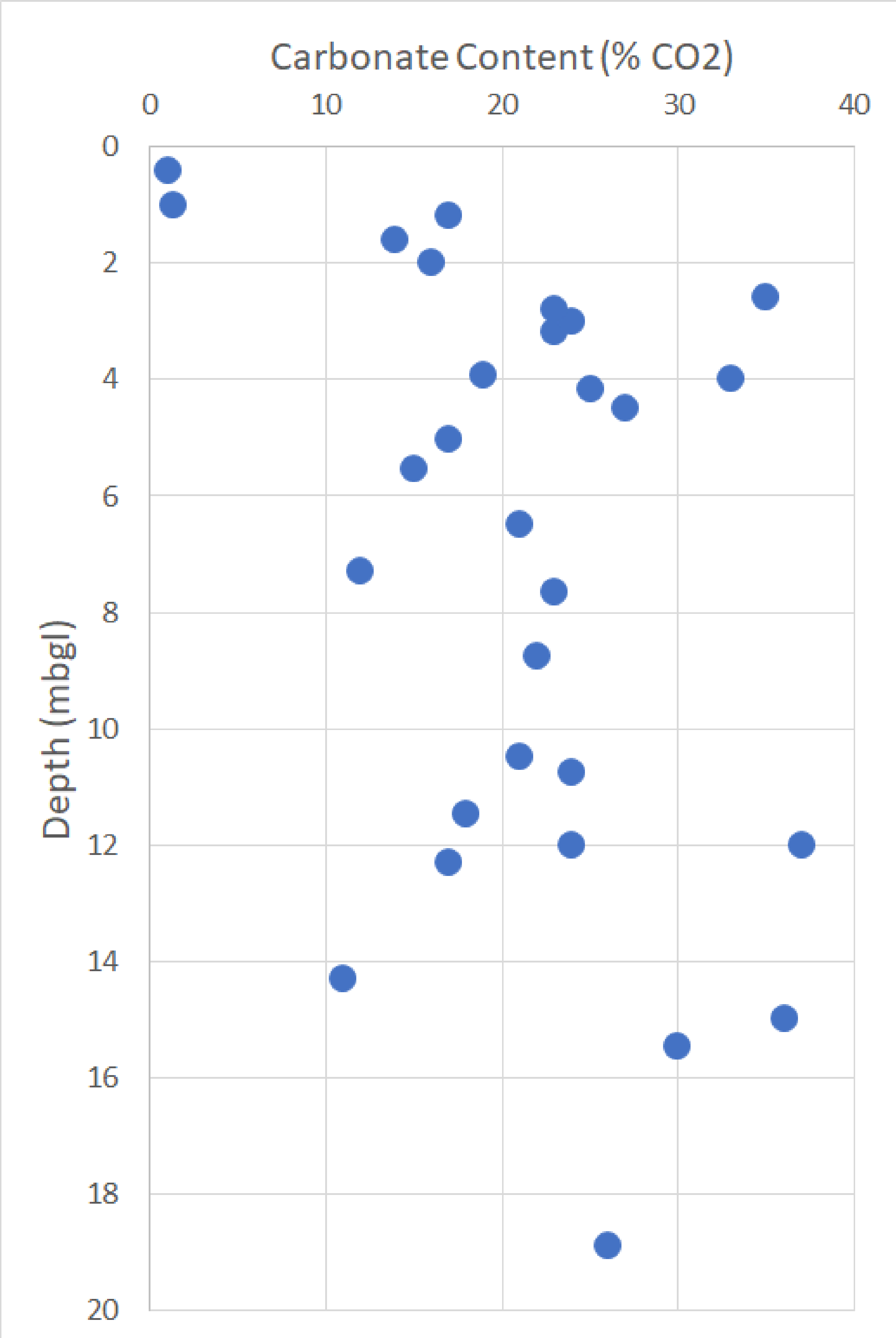
ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



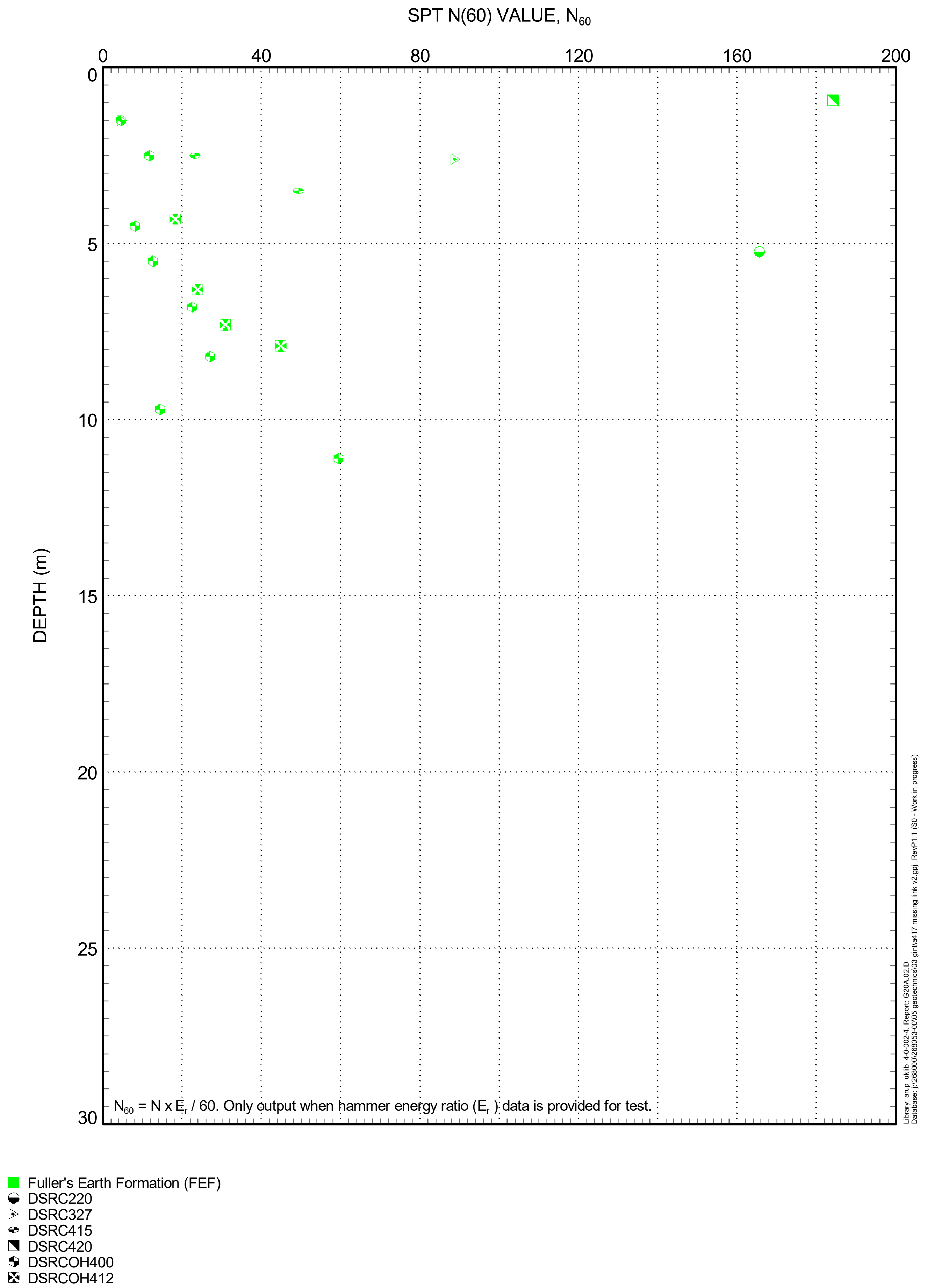
ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
FULLER'S EARTH FORMATION

FIGURE: F7.09

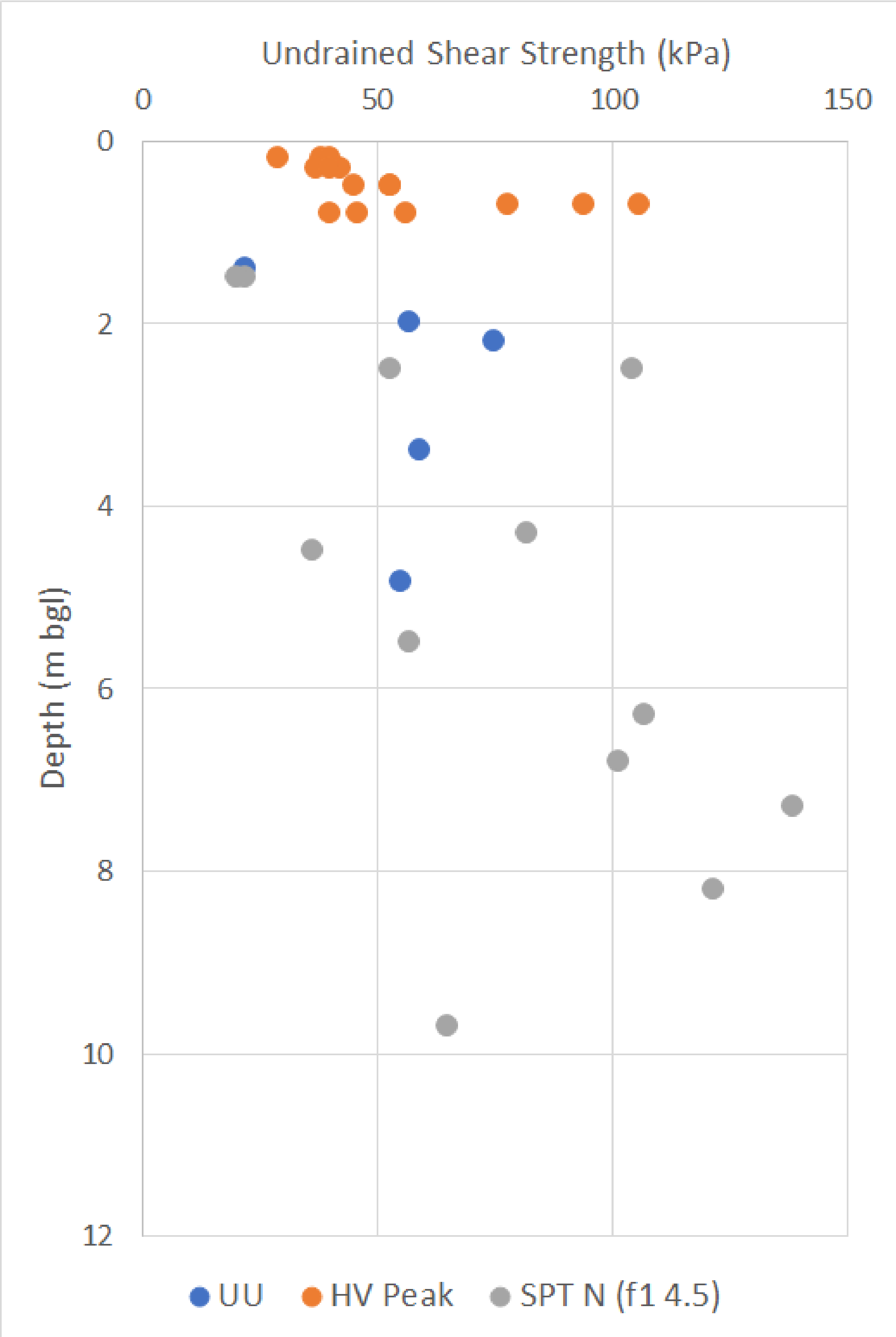


FULLER'S EARTH FORMATION
A417 - MISSING LINK
CARBONATE CONTENT
FIGURE: F7.10

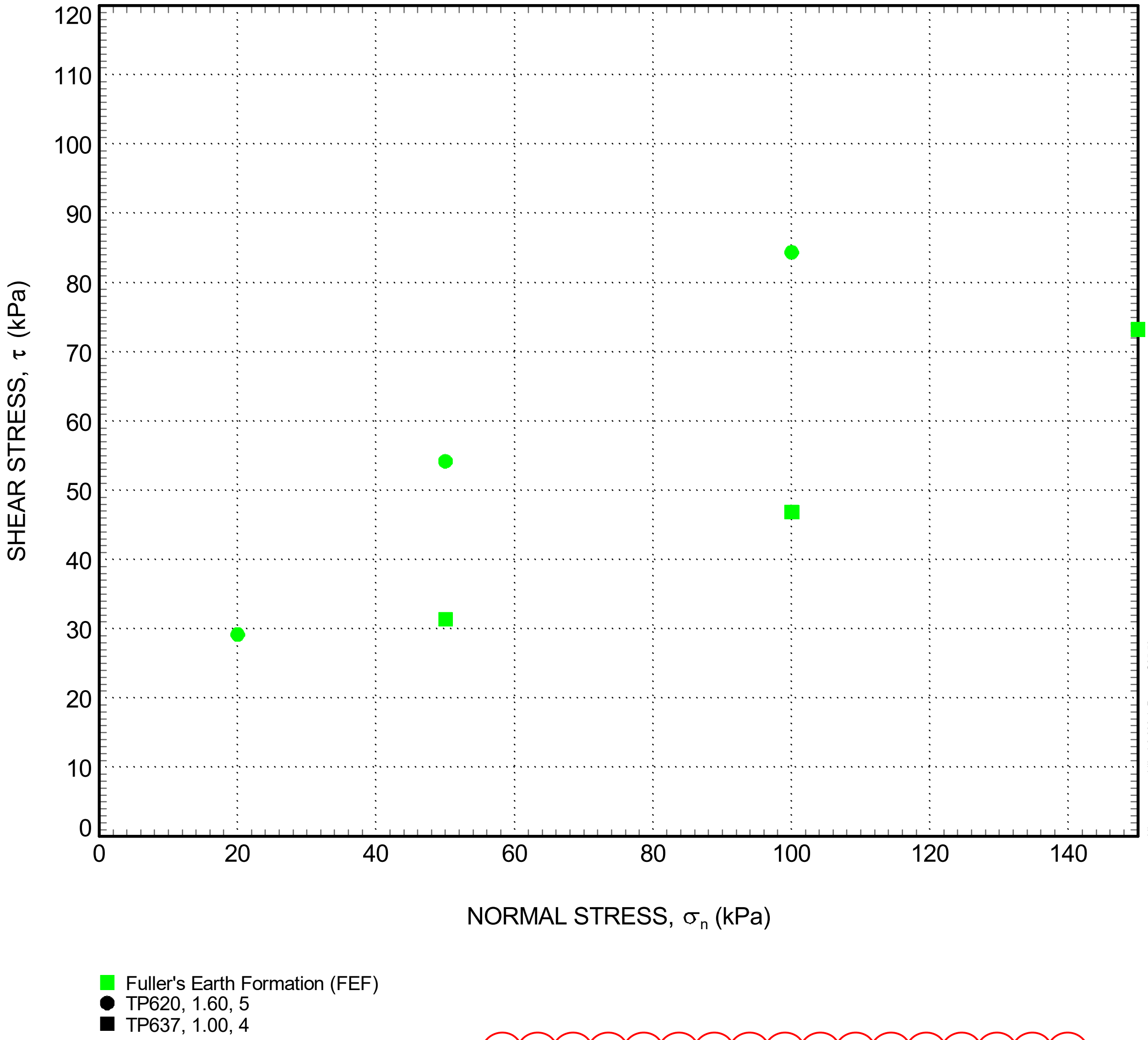


A417 - MISSING LINK
STANDARD PENETRATION TESTS
FULLER'S EARTH FORMATION

FIGURE: F7.11



FULLER'S EARTH FORMATION
A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH
FIGURE: F7.12

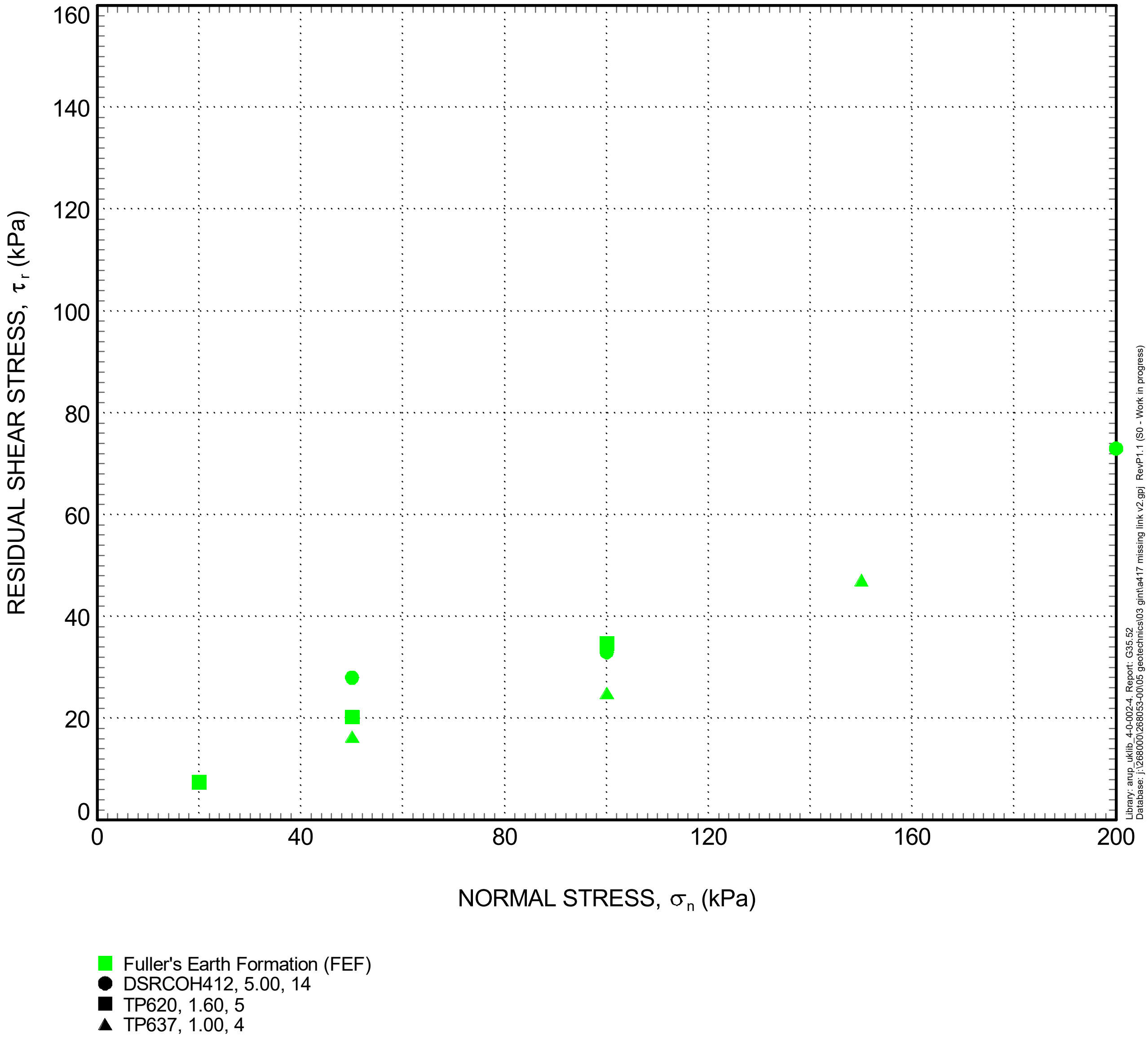


SHEAR BOX TEST REULTS - FEF

SEE F7.15 THAT INCOPORATES MORE DATA FROM HISTORICAL GI

A417 - MISSING LINK
SHEAR BOX TESTS
FULLER'S EARTH FORMATION

FIGURE: F7.13

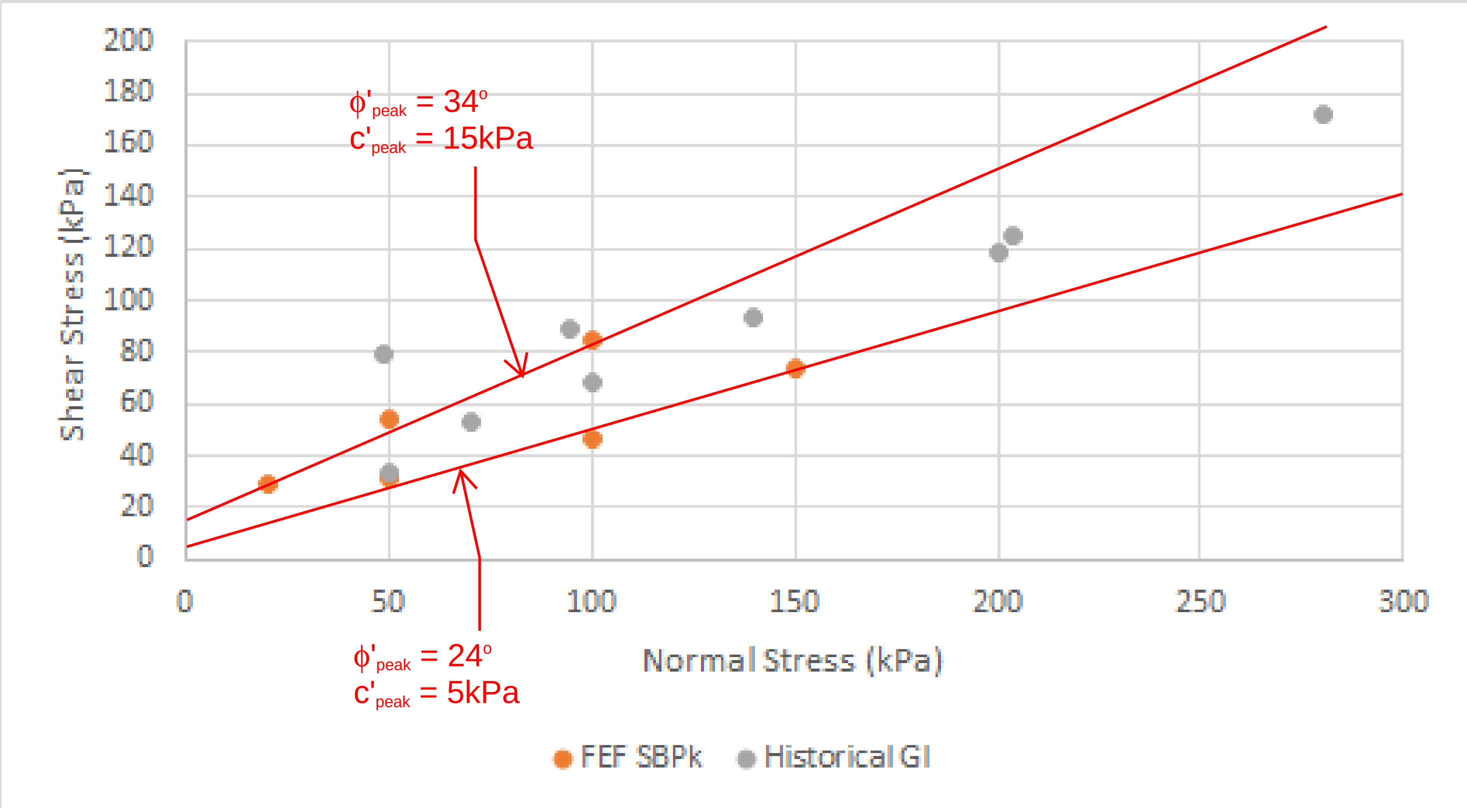


SHEAR BOX TEST REULTS - FEF

SEE F7.16 THAT INCOPORATES MORE DATA FROM HISTORICAL GI

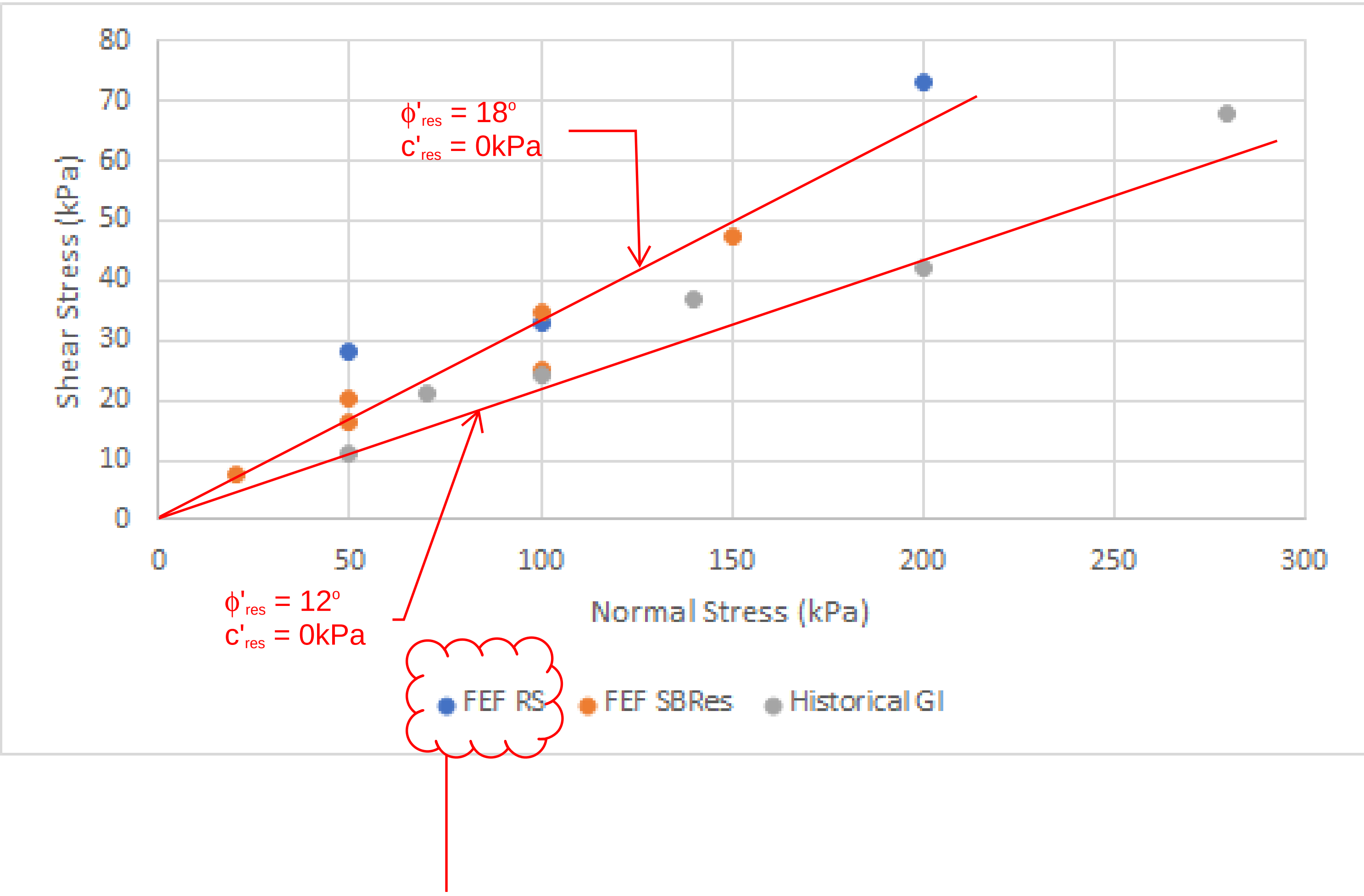
A417 - MISSING LINK
SHEAR BOX TESTS
FULLER'S EARTH FORMATION

FIGURE: F7.14



A417 - MISSING LINK
FULLER'S EARTH FORMATION
SHEARBOX TEST RESULTS - INCLUDING HISTORICAL TESTING FROM NETTLETON TO LATTON SCHEME (ONLY IN CLOSE VICINTY TO A417 SCHEME)

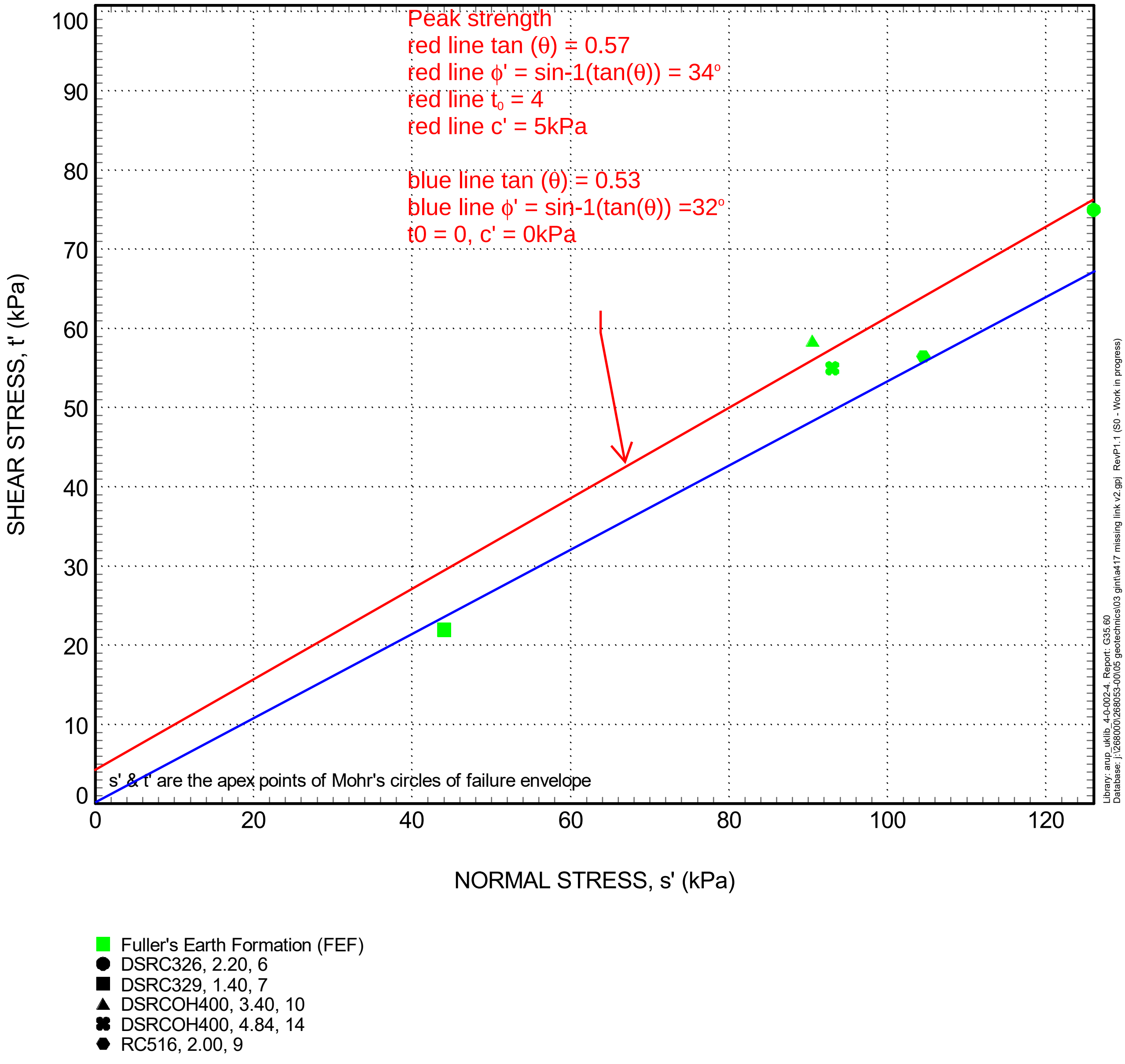
FIGURE: F7.15



Note - also includes ring shear as 1 test conducted

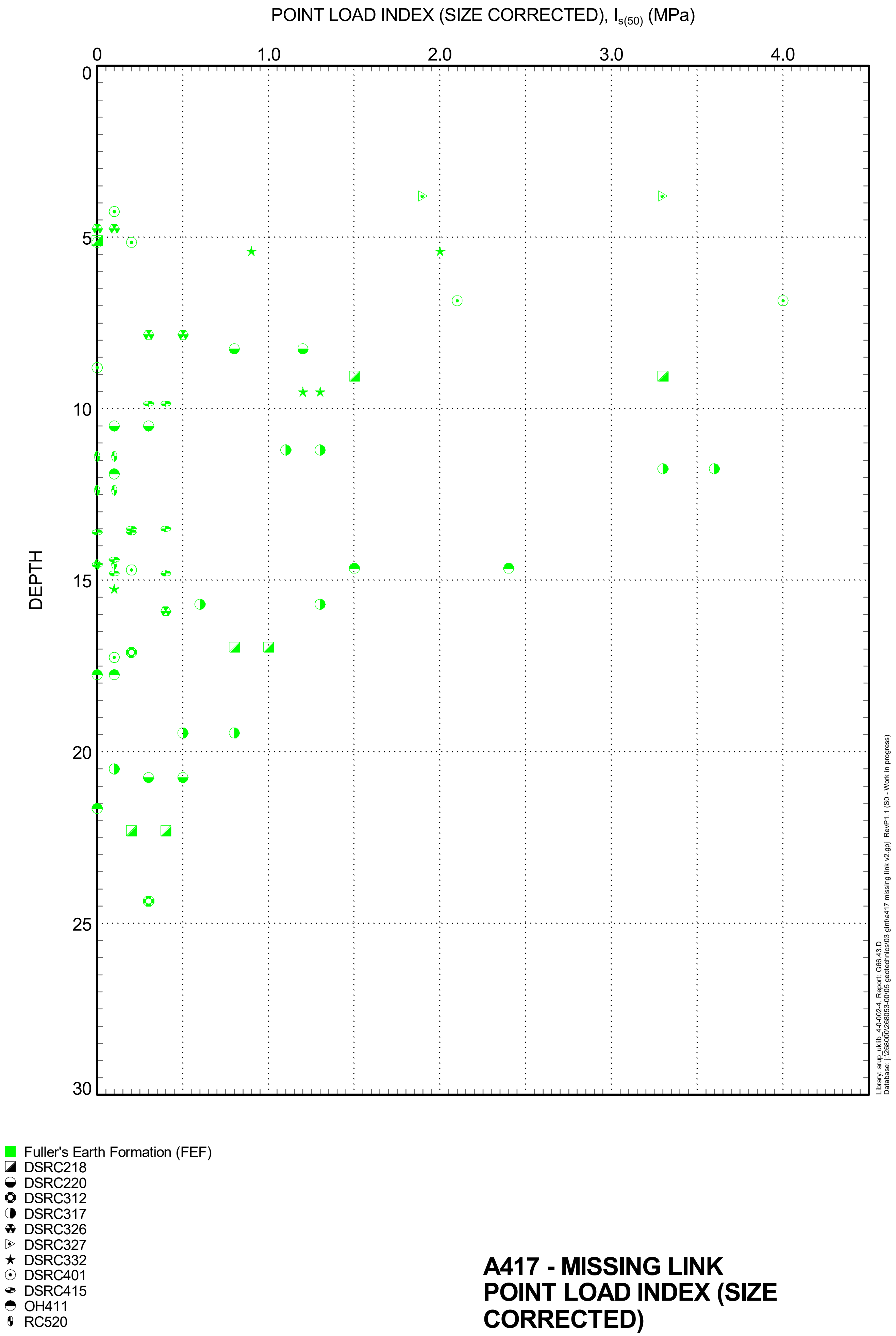
A417 - MISSING LINK
FULLER'S EARTH FORMATION
RESIDUAL SHEARBOX TEST RESULTS - INCLUDING HISTORICAL TESTING FROM NETTLETON TO LATTON SCHEME (ONLY IN CLOSE VICINTY TO A417 SCHEME)

FIGURE: F7.16



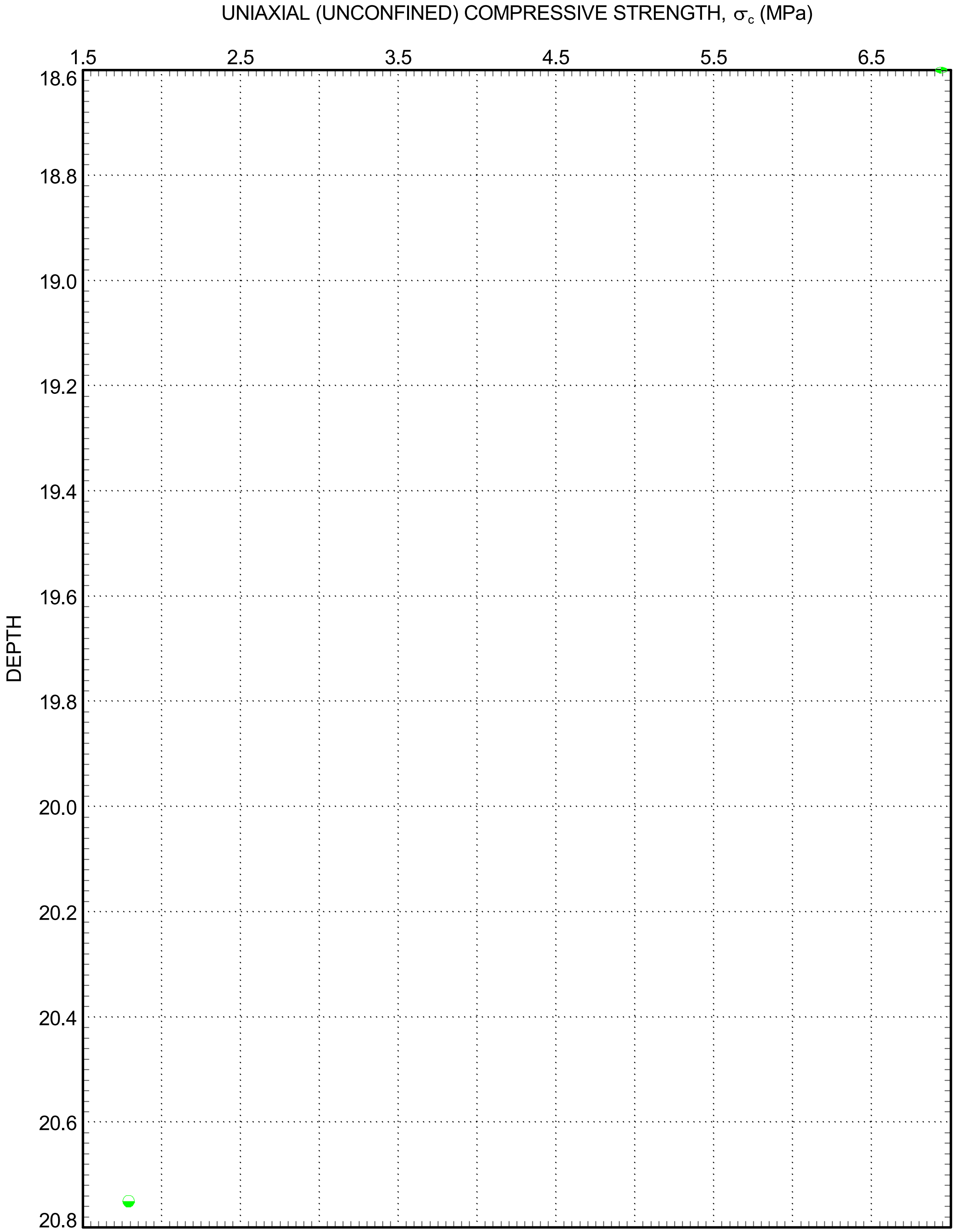
A417 - MISSING LINK
TRIAXIAL T' V S'
FULLER'S EARTH FORMATION

FIGURE: F7.17



A417 - MISSING LINK
POINT LOAD INDEX (SIZE CORRECTED)
FULLER'S EARTH FORMATION

FIGURE: F7.18



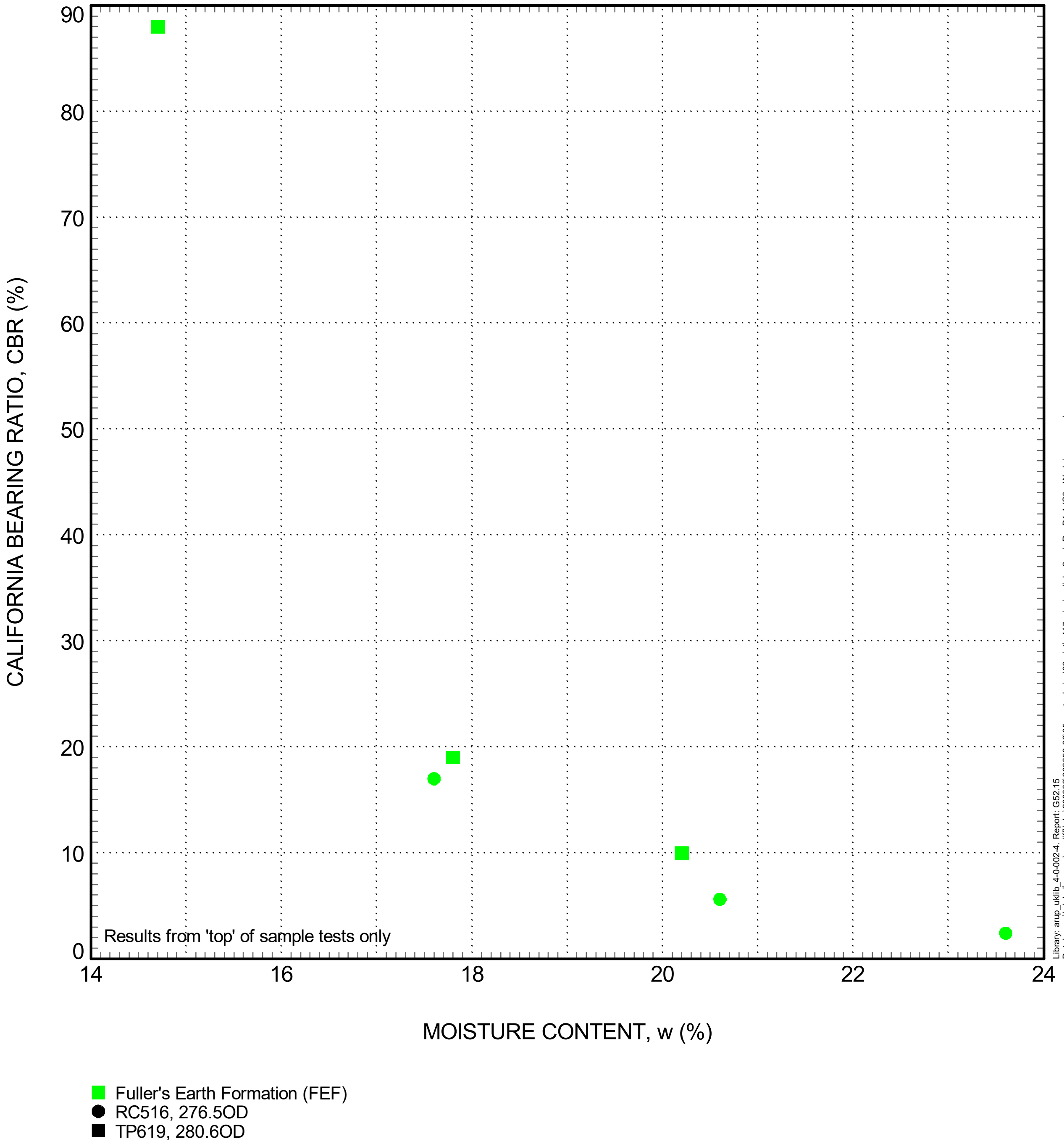
Fuller's Earth Formation (FEF)
DSRC220
DSRC415

Library: arup_uklib_4-0-002-4, Report: G66.41.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNIAXIAL COMPRESSIVE STRENGTH
FULLER'S EARTH FORMATION

FIGURE: F7.19



Library: arup_uklib_4-0-002-4. Report: G52.15
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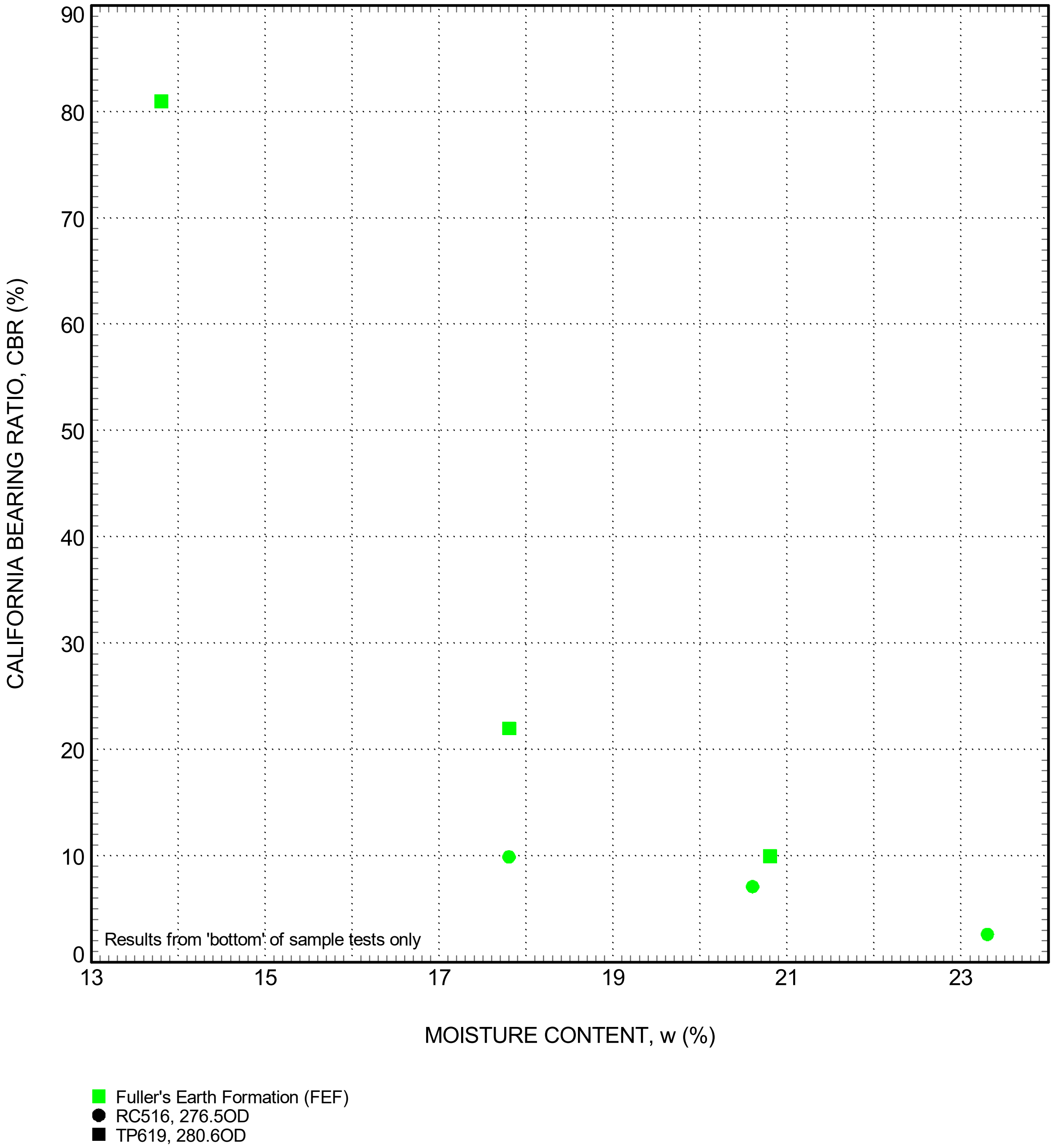
ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
LAB CBR VS MOISTURE CONTENT
FULLER'S EARTH FORMATION

FIGURE: F7.20



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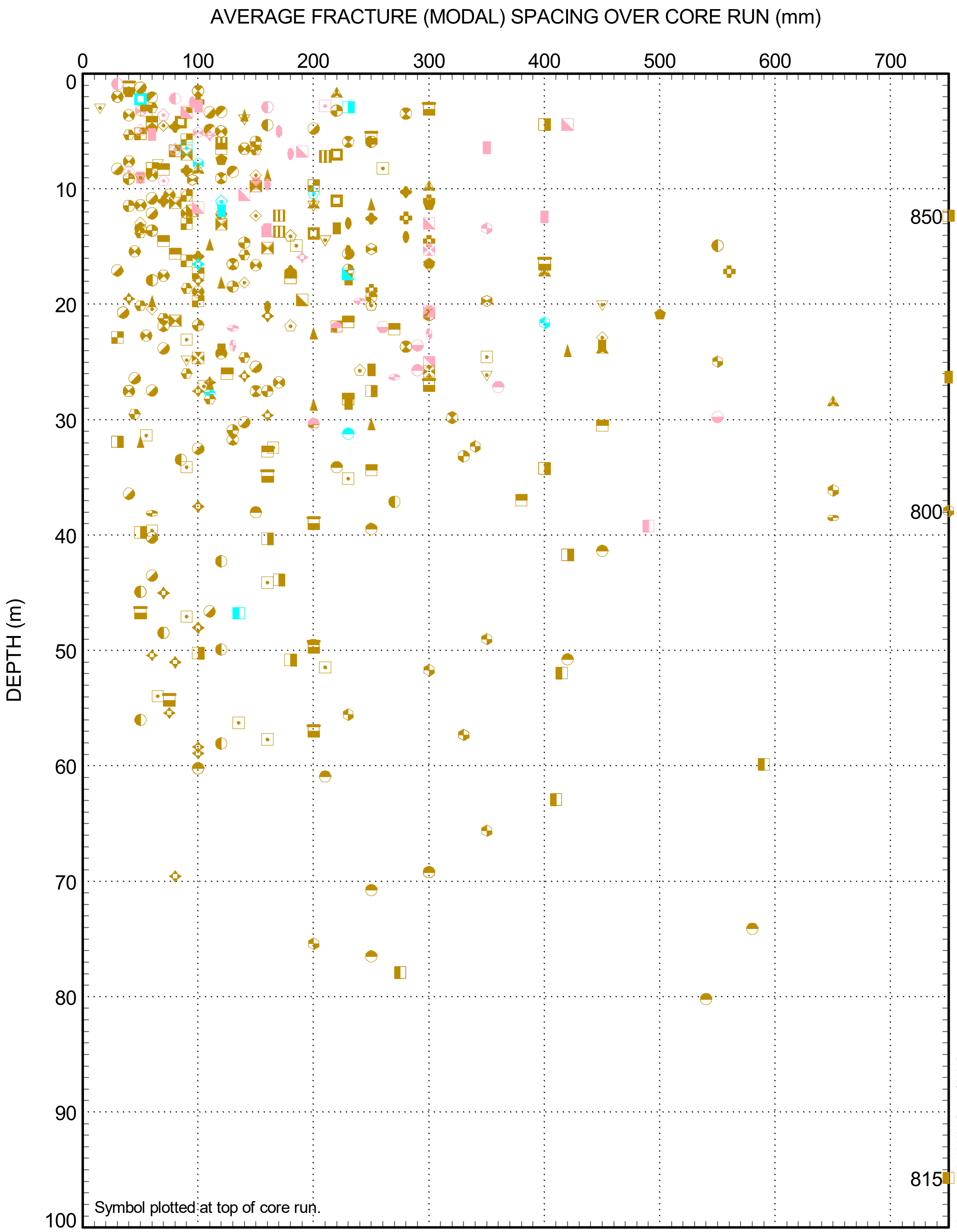
Database: \\global\europe\cardiff\jobs\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
LAB CBR VS MOISTURE CONTENT
FULLER'S EARTH FORMATION

FIGURE: F7.21

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

F.8 Inferior Oolite Group

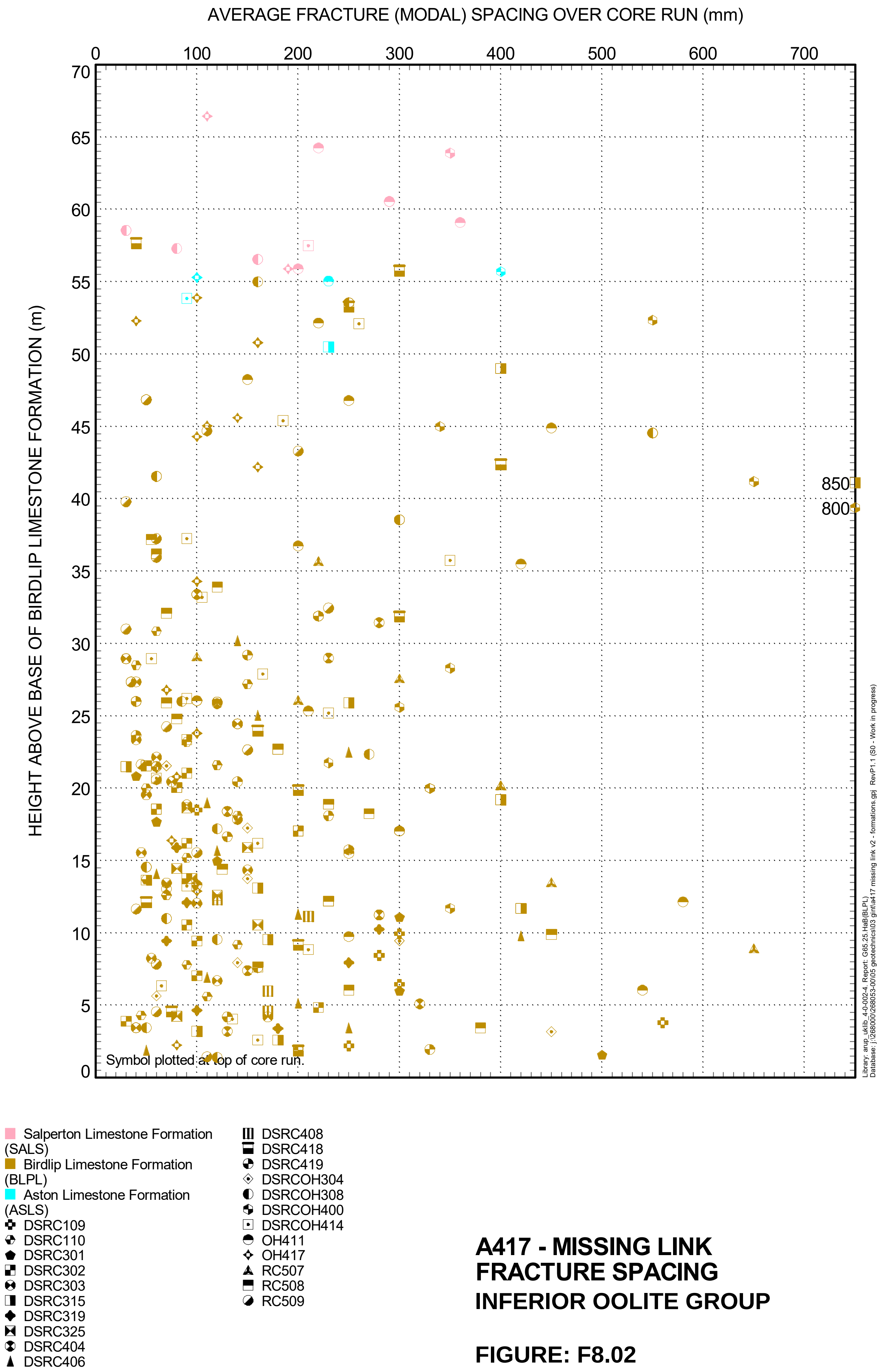


Salperton Limestone Formation (SALS)
Birdlip Limestone Formation (BLPL)
Aston Limestone Formation (ASLS)
DSRC109
DSRC110
DSRC220
DSRC301
DSRC302
DSRC303
DSRC310
DSRC311
DSRC314
DSRC315
DSRC319
DSRC325
DSRC329
DSRC404
DSRC406
DSRC408
DSRC415
DSRC418
DSRC419
DSRC420
DSRCOH304
DSRCOH308
DSRCOH308A
DSRCOH400
DSRCOH412
DSRCOH414
OH411
OH413
OH417
RC504
RC506
RC507
RC508
RC509
RC514
RC516
RC520

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
FRACTURE SPACING
INFERIOR OOLITE GROUP

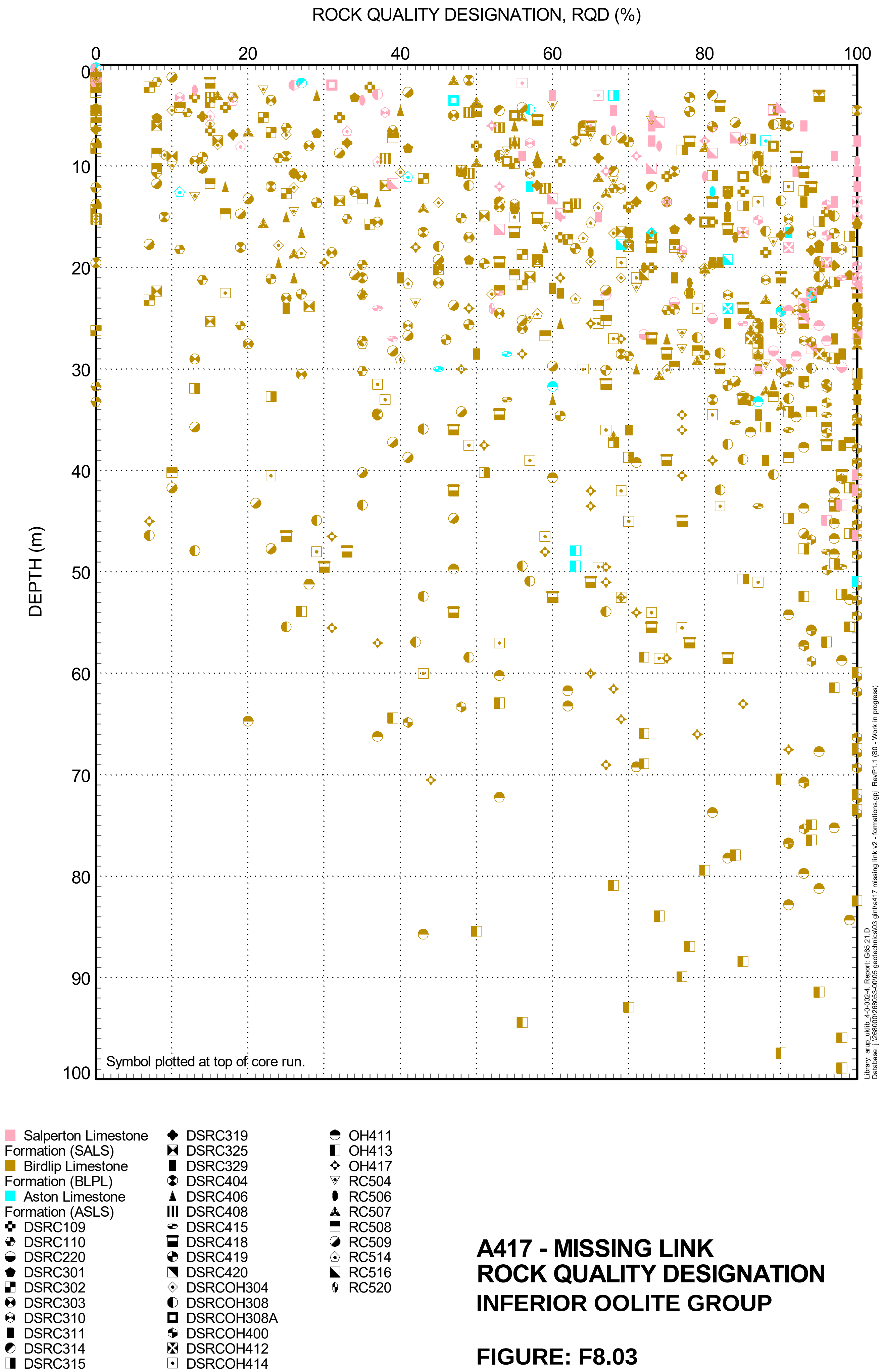
FIGURE: F8.01



Library: arup_uklib_4-0-002-4, Report: G65.25.HaB(BLPL)
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)
ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
FRACTURE SPACING
INFERIOR OOLITE GROUP

FIGURE: F8.02

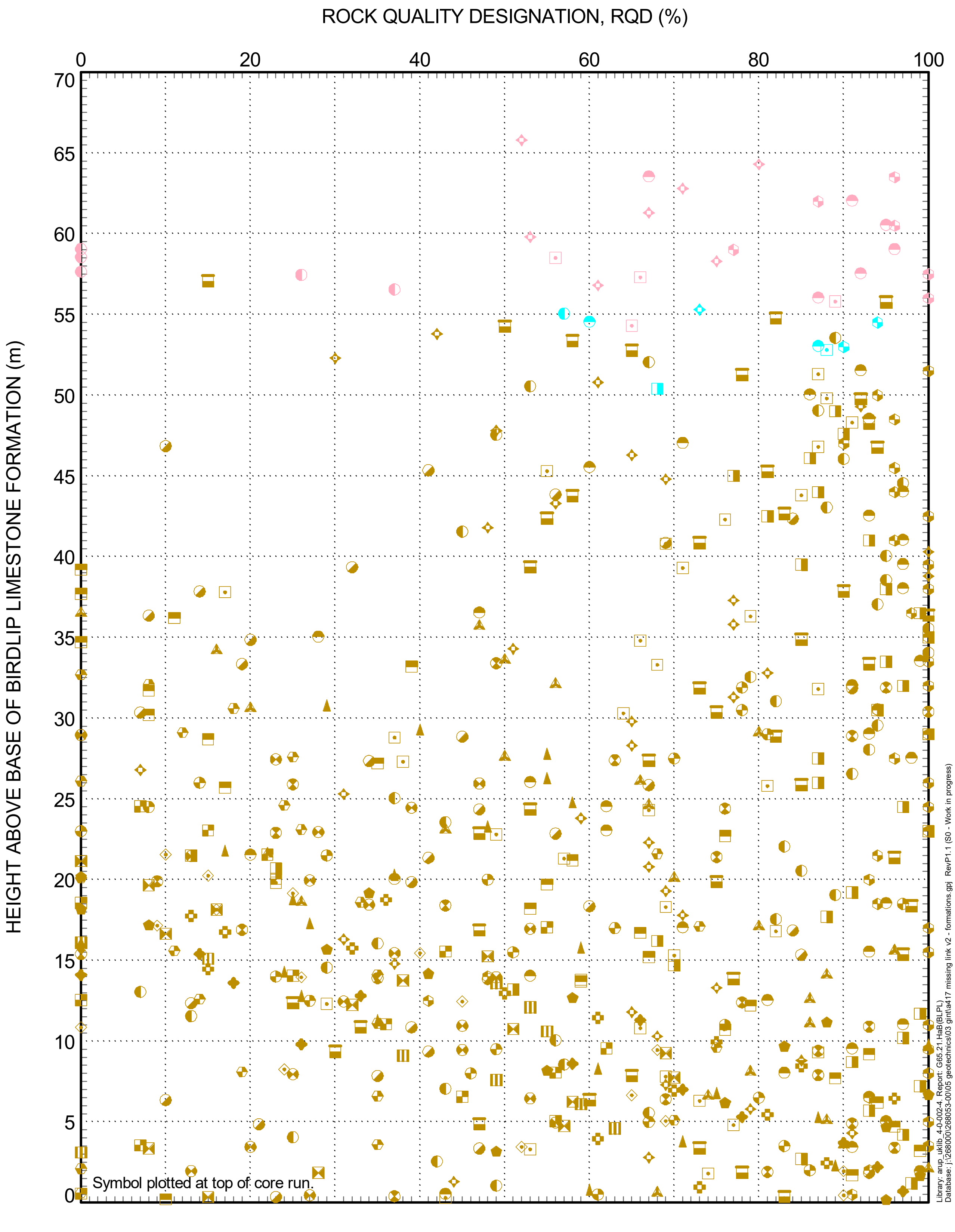


Library: arup_uklib_4-0-002-4. Report: G65.21.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ROCK QUALITY DESIGNATION
INFERIOR OOLITE GROUP

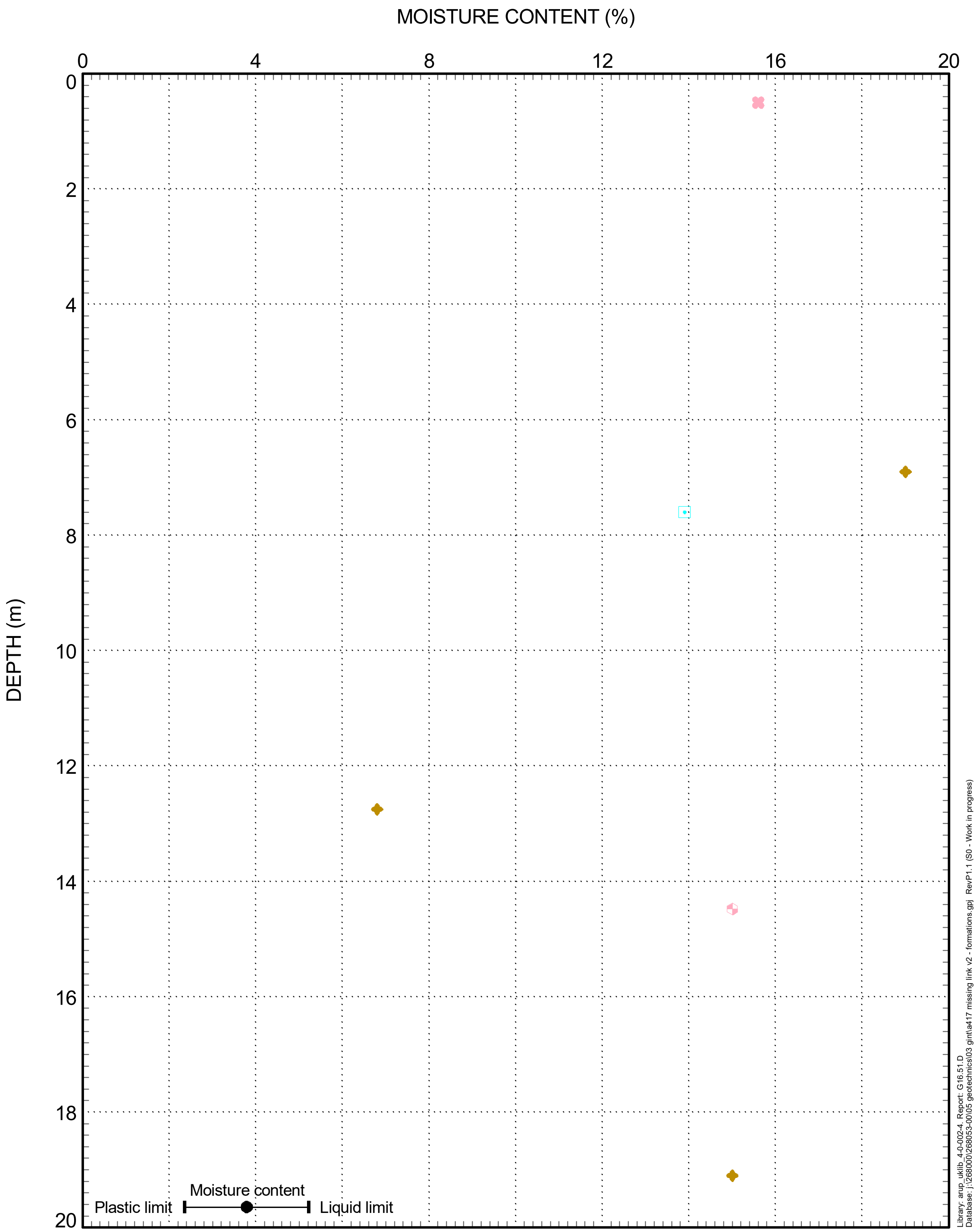
FIGURE: F8.03



ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ROCK QUALITY DESIGNATION
INFERIOR OOLITE GROUP

FIGURE: F8.04

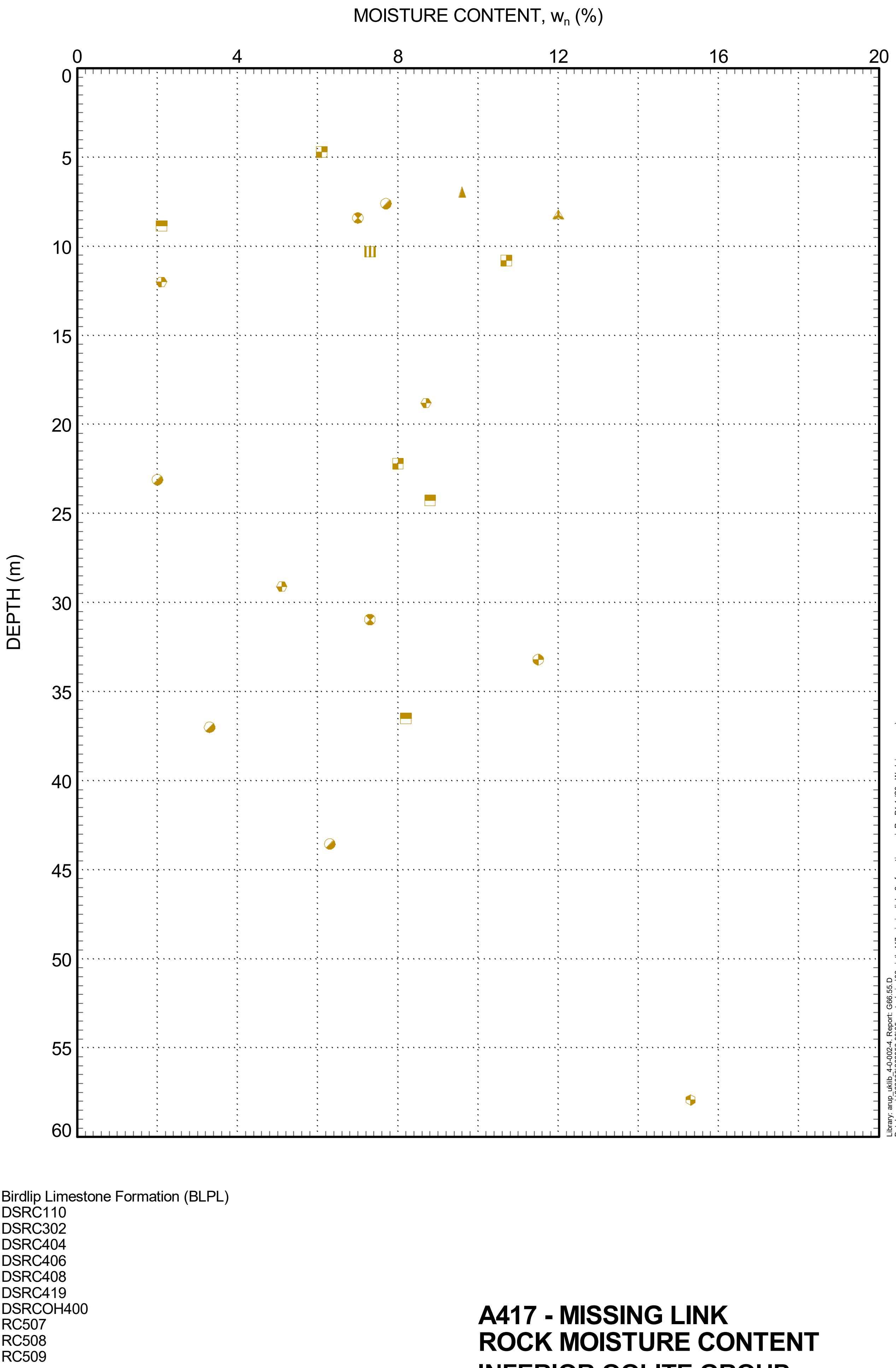


Salperton Limestone Formation (SALS)
Birdlip Limestone Formation (BLPL)
Aston Limestone Formation (ASLS)
DSRC319
DSRCOH400
DSRCOH414
TP634

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
MOISTURE CONTENT
INFERIOR OOLITE GROUP

FIGURE: F8.05

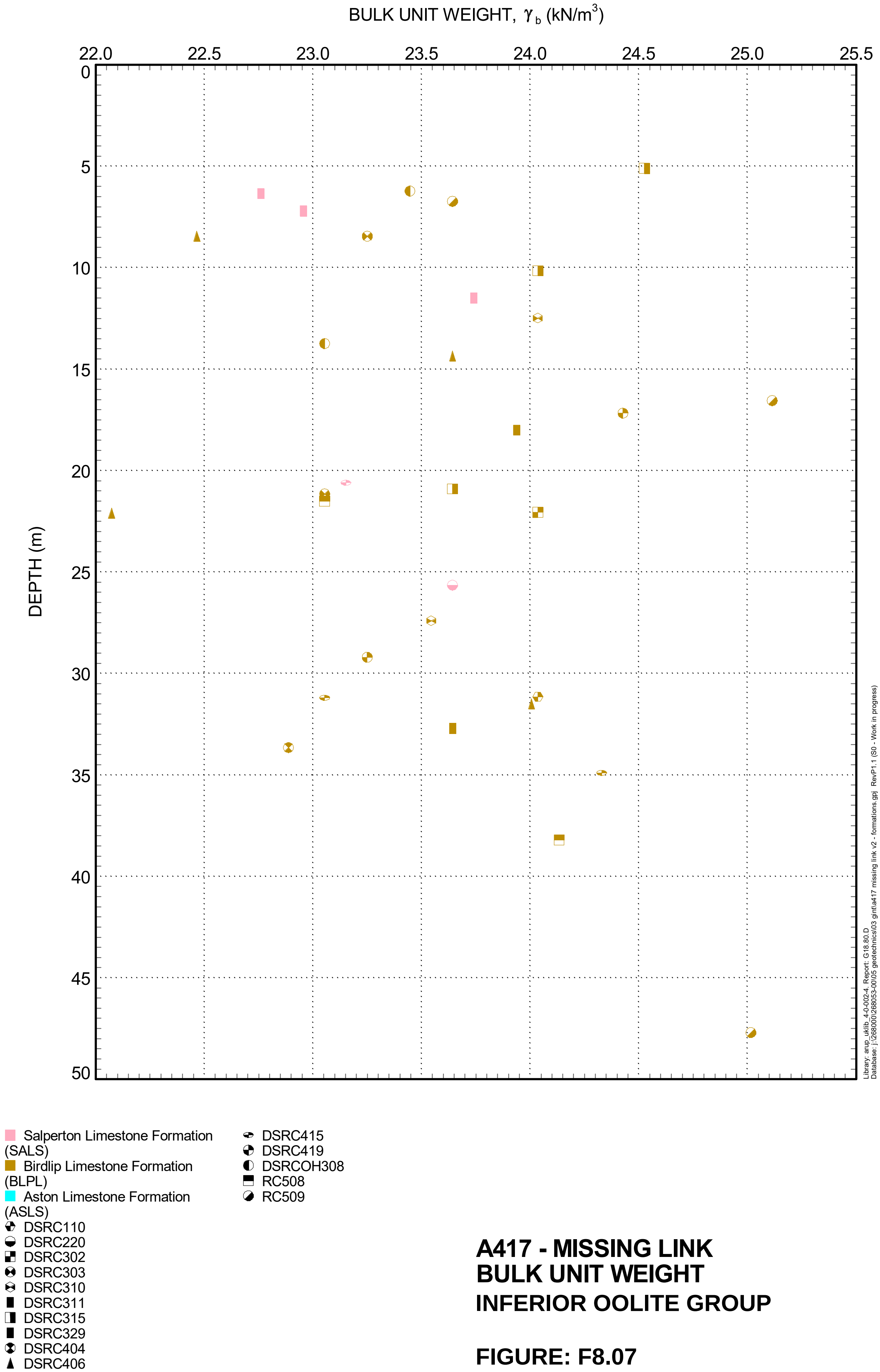


Library: arup_uklib_4-0-002-4. Report: G66.55.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

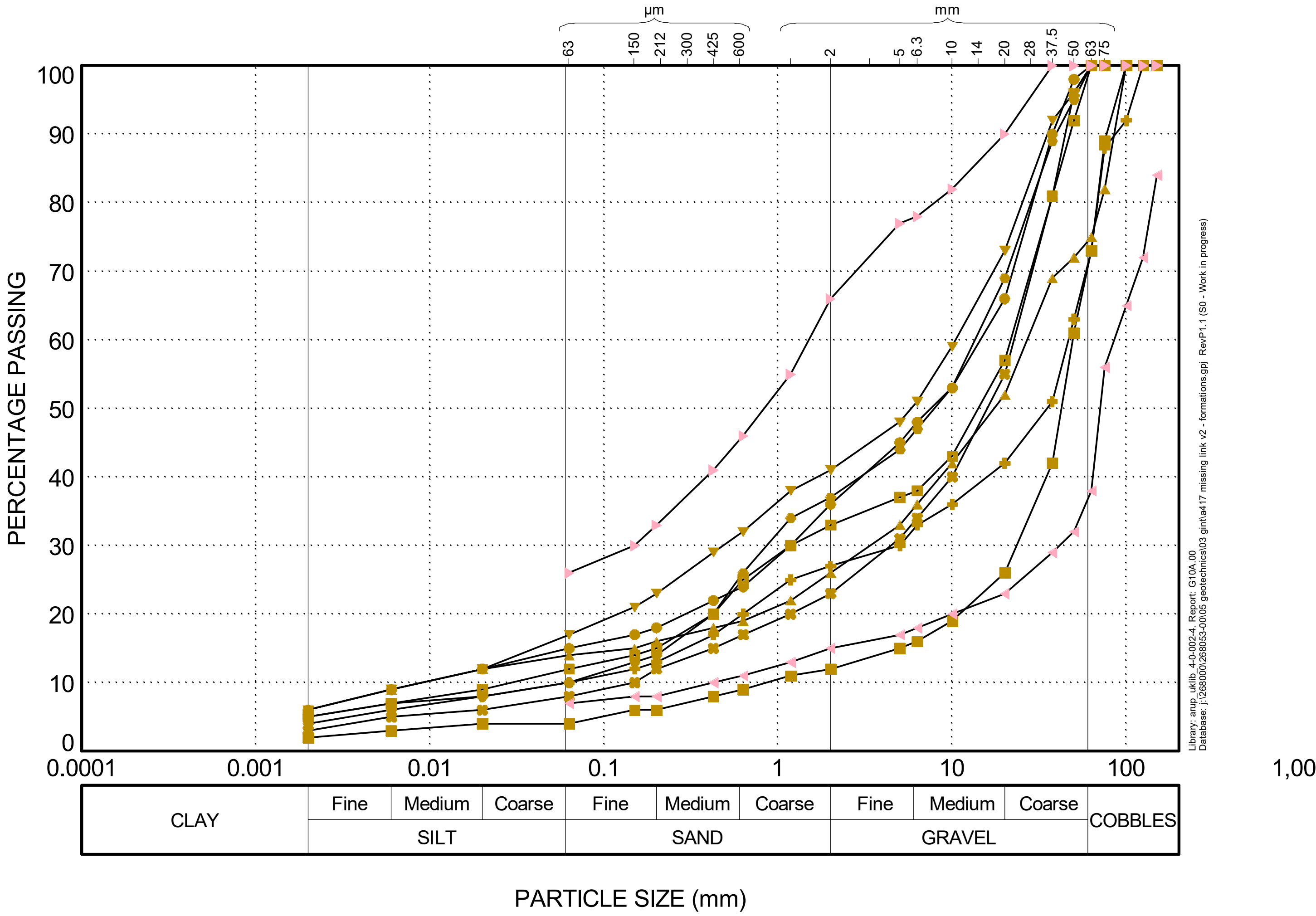
A417 - MISSING LINK
ROCK MOISTURE CONTENT
INFERIOR OOLITE GROUP

FIGURE: F8.06



A417 - MISSING LINK
BULK UNIT WEIGHT
INFERIOR OOLITE GROUP

FIGURE: F8.07



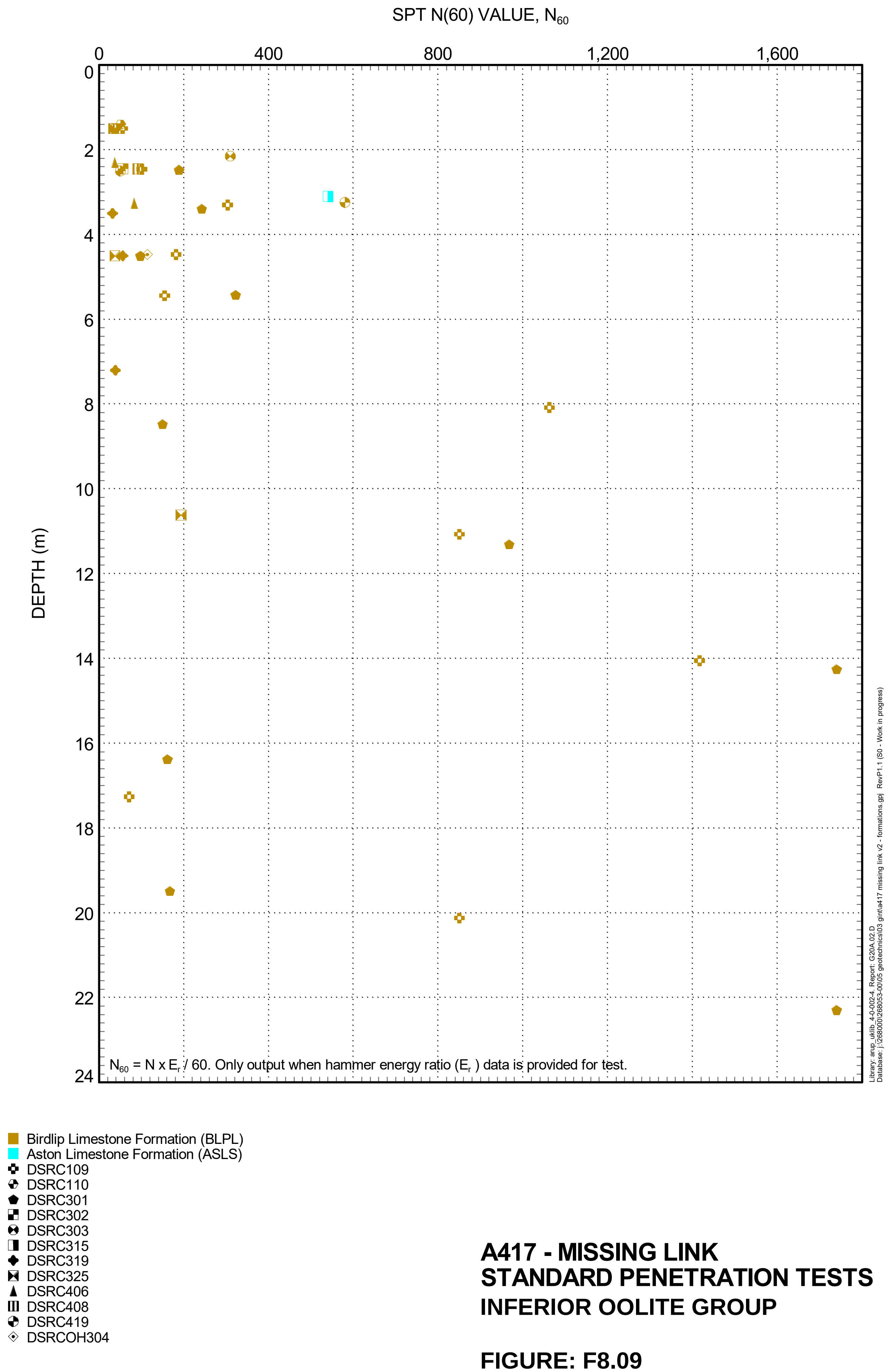
Salperton Limestone Formation (SALS)
Birdlip Limestone Formation (BLPL)
● DSRC109, 1.20, 4
■ DSRC110, 1.00, 7
▲ DSRC301, 4.20, 8
✖ DSRC302, 0.30, 3
⬢ DSRC302, 0.90, 7
▼ DSRC303, 0.30, 3
✚ DSRC303, 1.00, 6
◘ RC508, 0.80, 5
◀ TP602, 0.50, 4
▶ TP634, 0.50, 3

Library: arup_uklib_4-0-002-4, Report: G10A.00
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
INFERIOR OOLITE GROUP

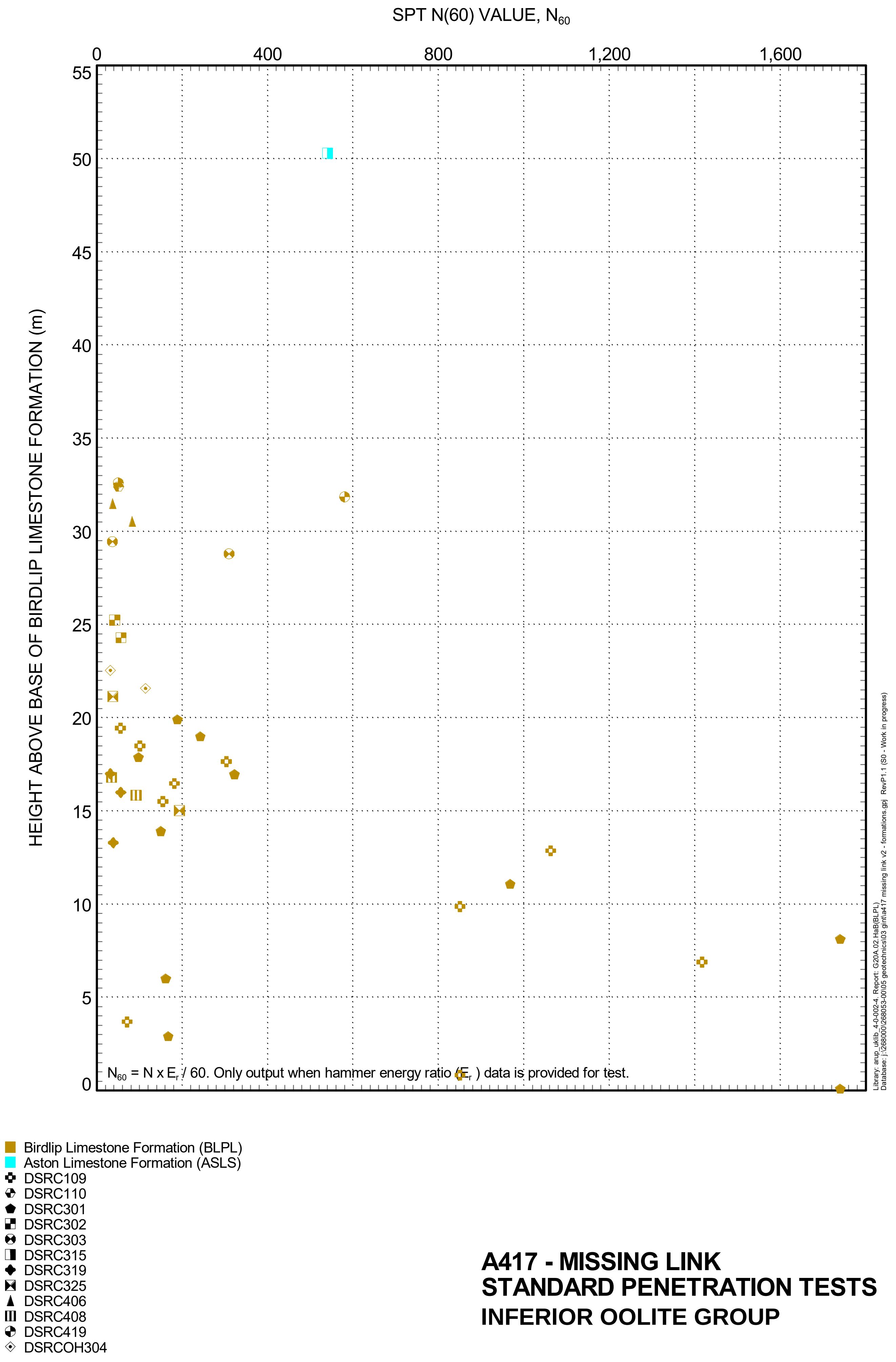
FIGURE: F8.08



ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

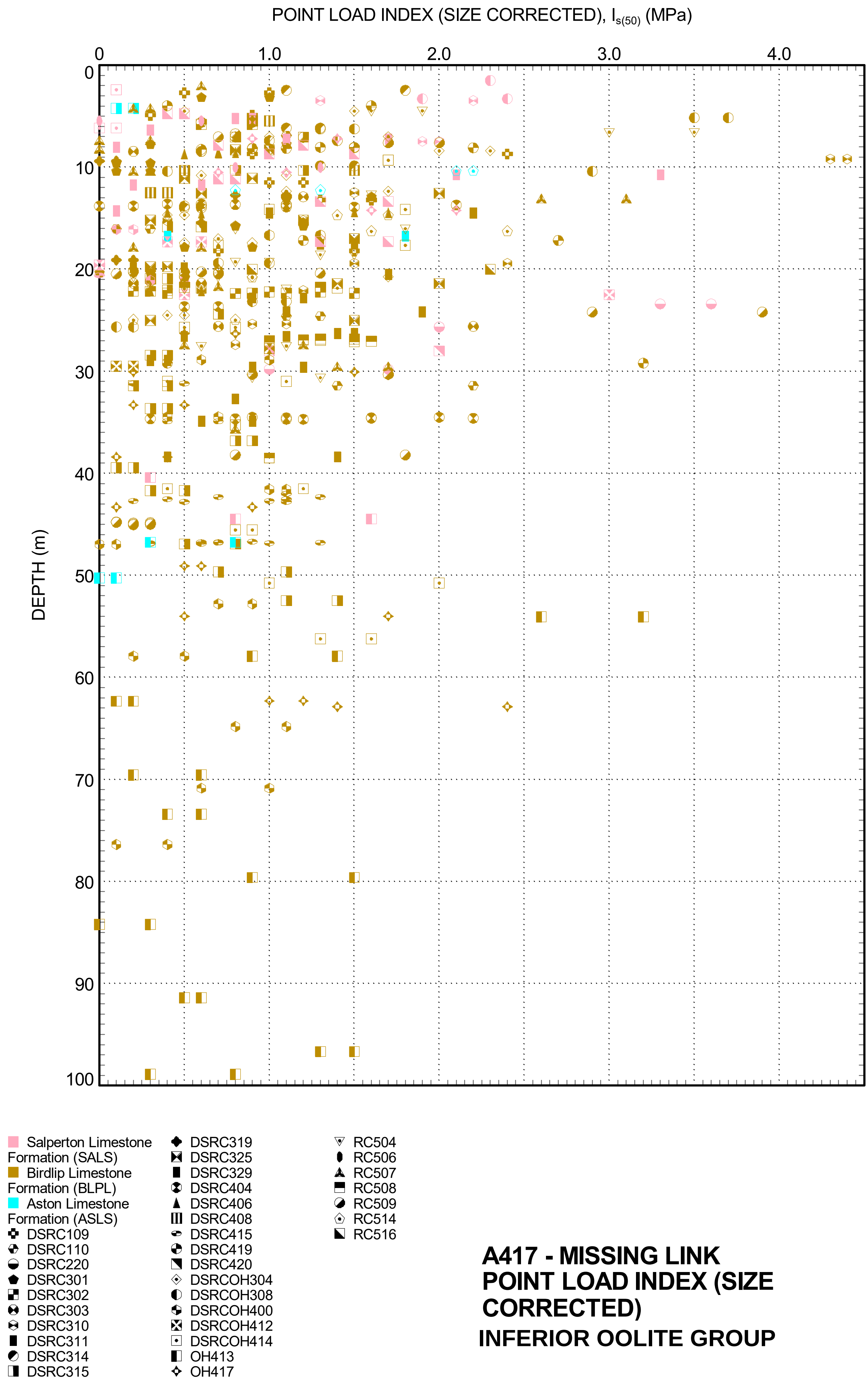
A417 - MISSING LINK
STANDARD PENETRATION TESTS
INFERIOR OOLITE GROUP

FIGURE: F8.09



A417 - MISSING LINK
STANDARD PENETRATION TESTS
INFERIOR OOLITE GROUP

FIGURE: F8.10

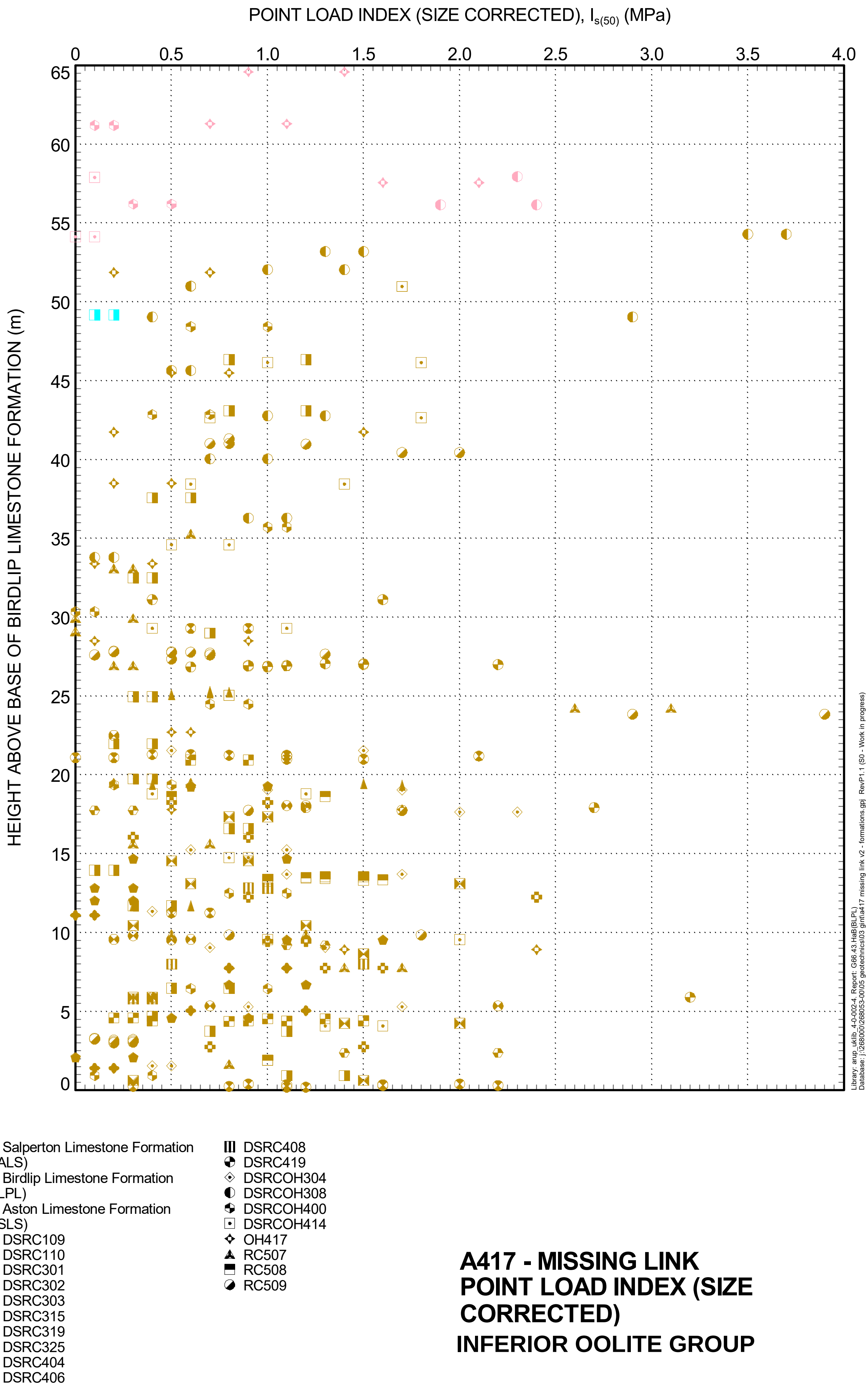


ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

Library: arup_uklib_4-0-002-4, Report: G66.43.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
POINT LOAD INDEX (SIZE CORRECTED)
INFERIOR OOLITE GROUP

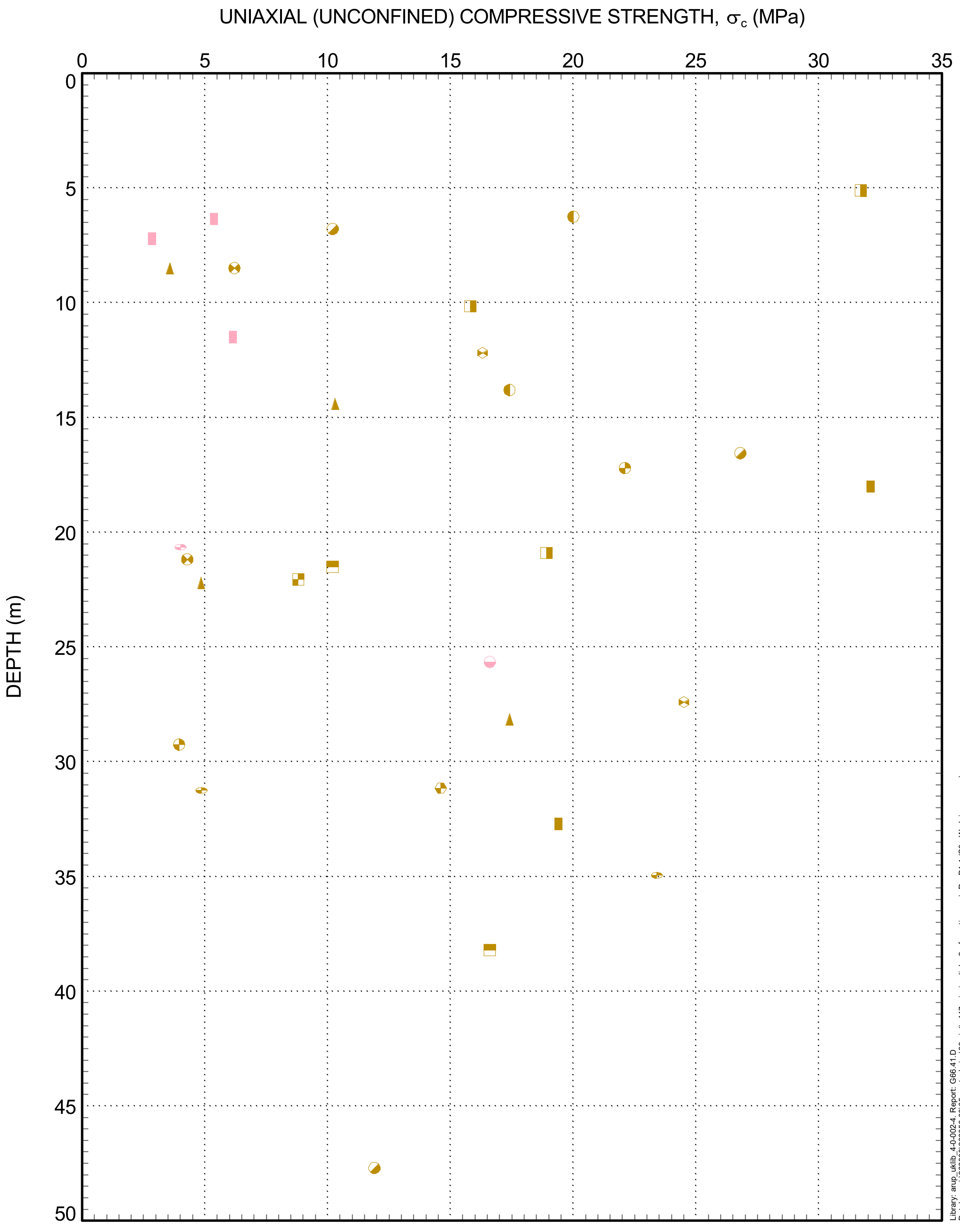
FIGURE: F8.11



ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
POINT LOAD INDEX (SIZE CORRECTED)
INFERIOR OOLITE GROUP

FIGURE: F8.12



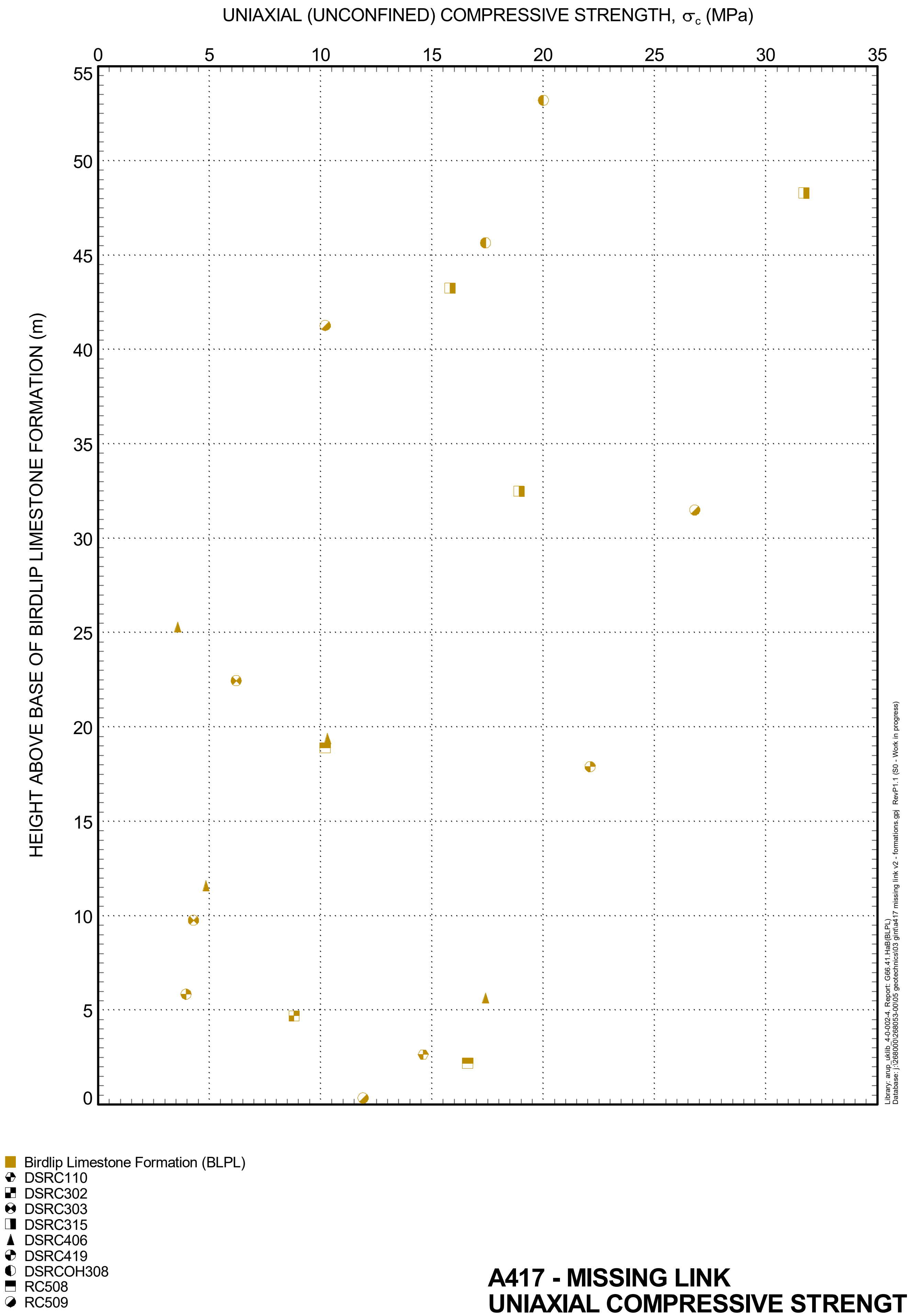
Salperton Limestone Formation (SALS)
Birdlip Limestone Formation (BLPL)
DSRC110
DSRC220
DSRC302
DSRC303
DSRC310
DSRC311
DSRC315
DSRC329
DSRC406
DSRC415
DSRC419
DSRCOH308
RC508
RC509

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

Library: arup_uklib_4-0-002-4, Report: G66.41.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

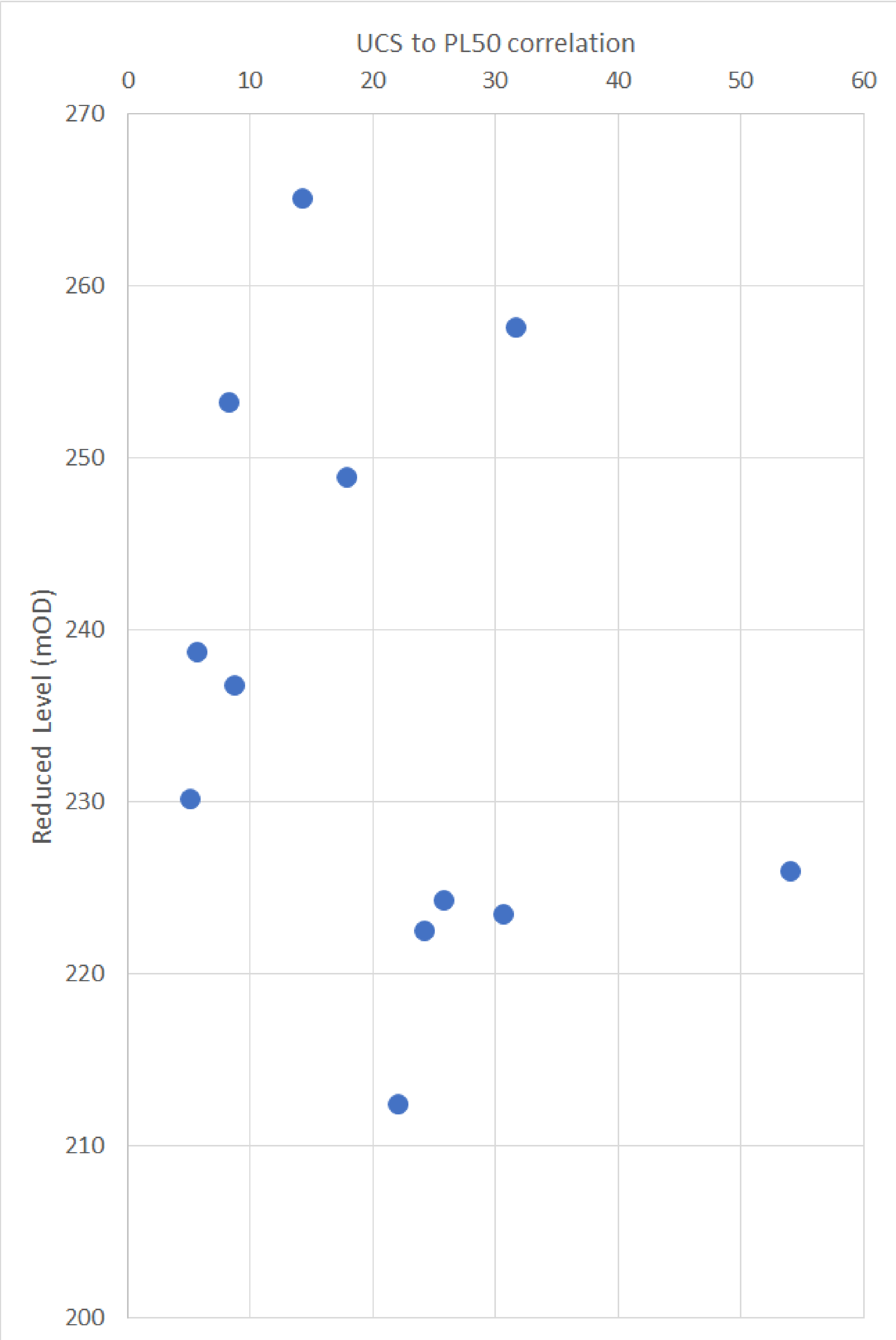
A417 - MISSING LINK
UNIAXIAL COMPRESSIVE STRENGTH
ASTON LIMESTONE FORMATION &
INFERIOR OOLITE GROUP

FIGURE: F8.13



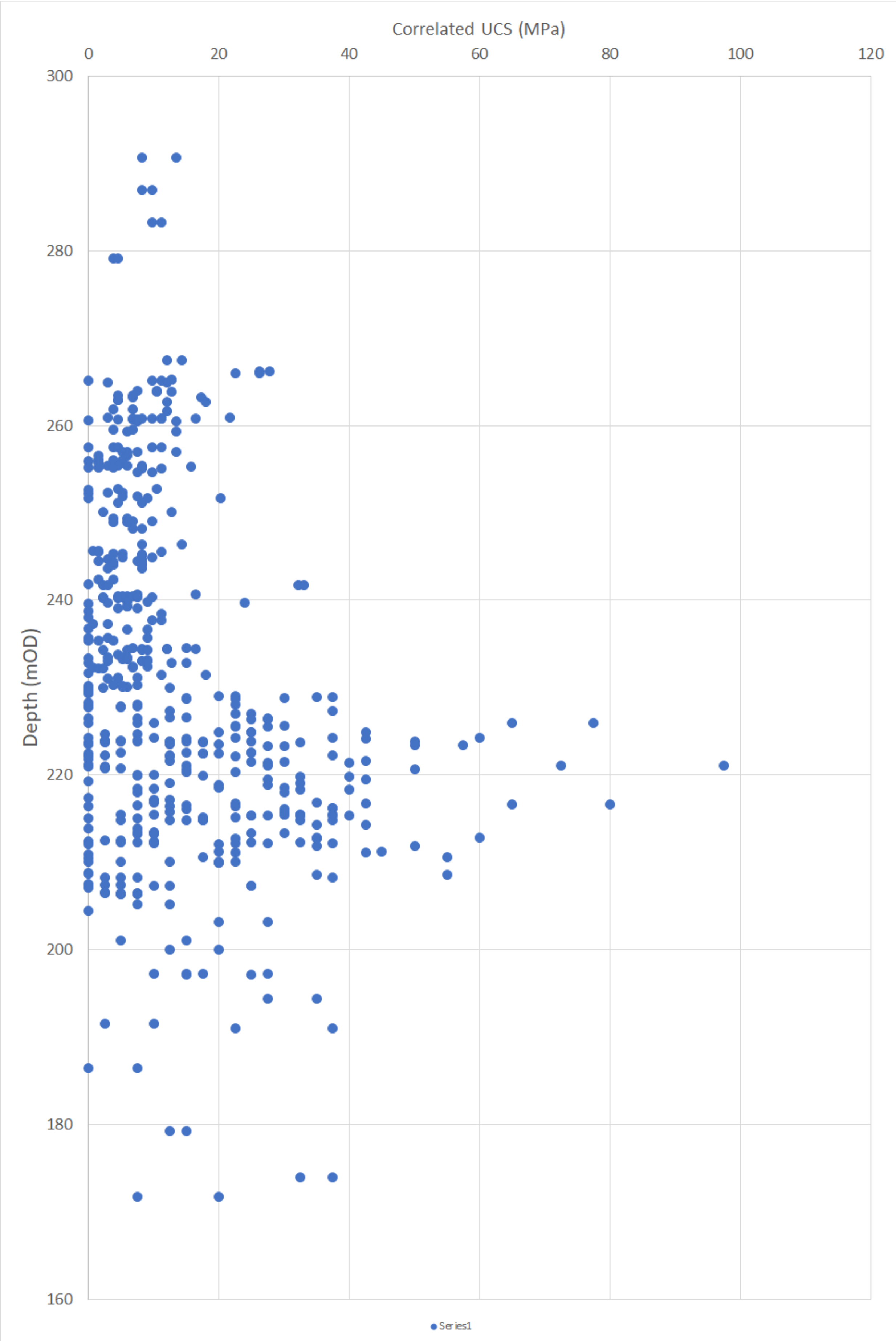
A417 - MISSING LINK
UNIAXIAL COMPRESSIVE STRENGTH
INFERIOR OOLITE GROUP

FIGURE: F8.14



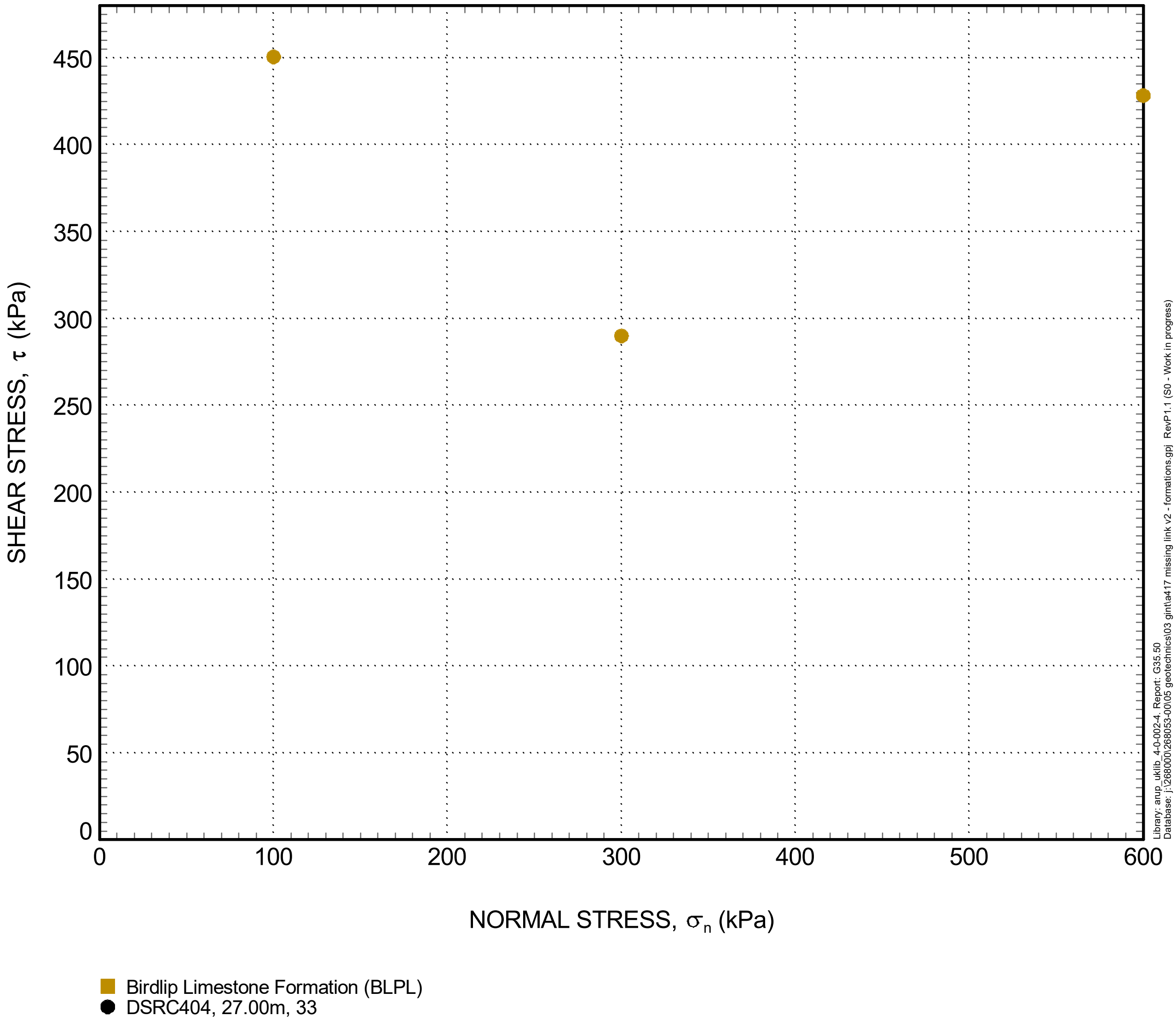
A417 - MISSING LINK
UCS TO PL50 CORRELATION
INFERIOR OOLITE GROUP

FIGURE: F8.15



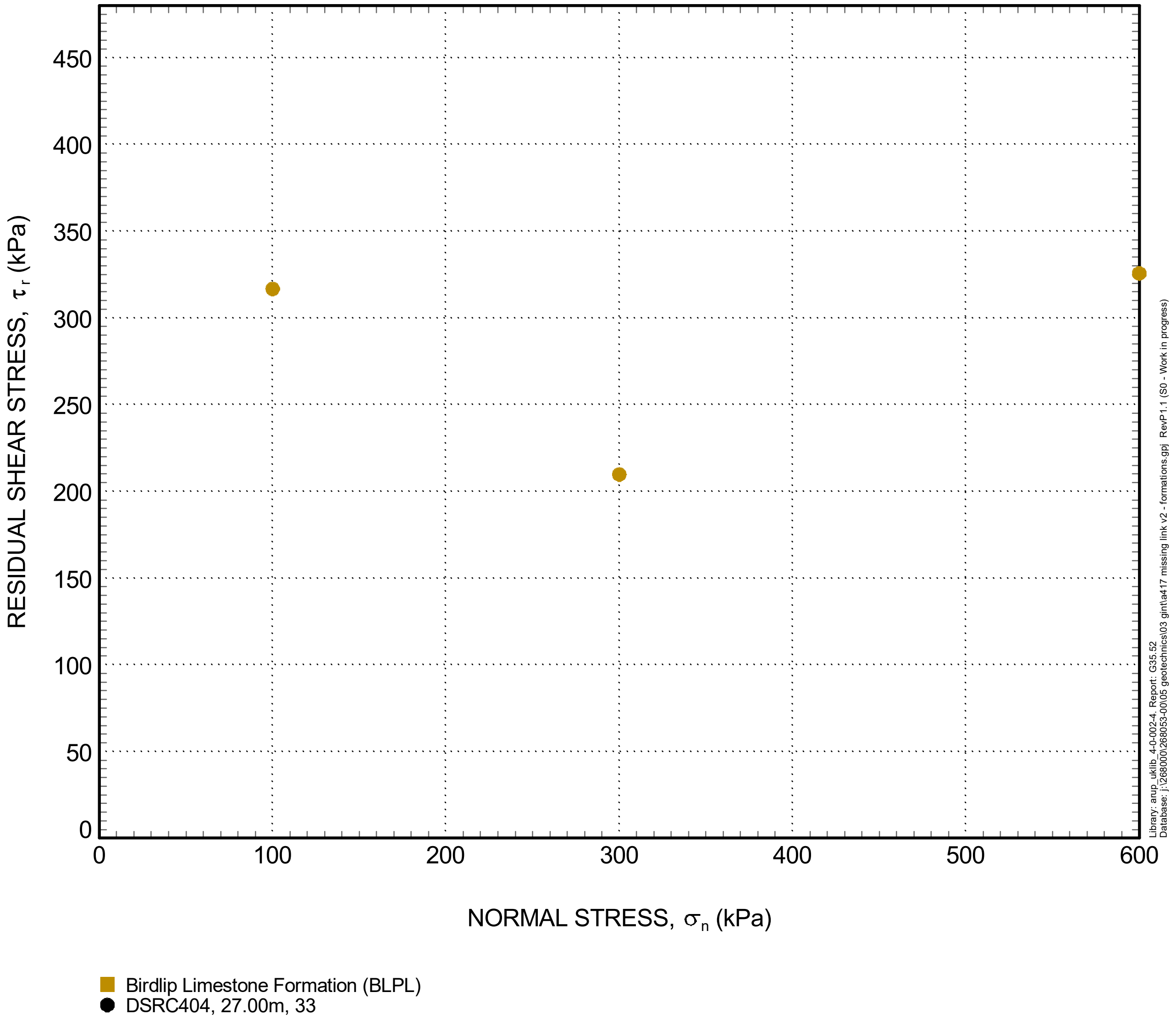
A417 - MISSING LINK
UCS FROM UCS/POINT LOAD CORRELATION
INFERIOR OOLITE GROUP

FIGURE: F8.16



A417 - MISSING LINK
SHEAR BOX TESTS
INFERIOR OOLITE GROUP

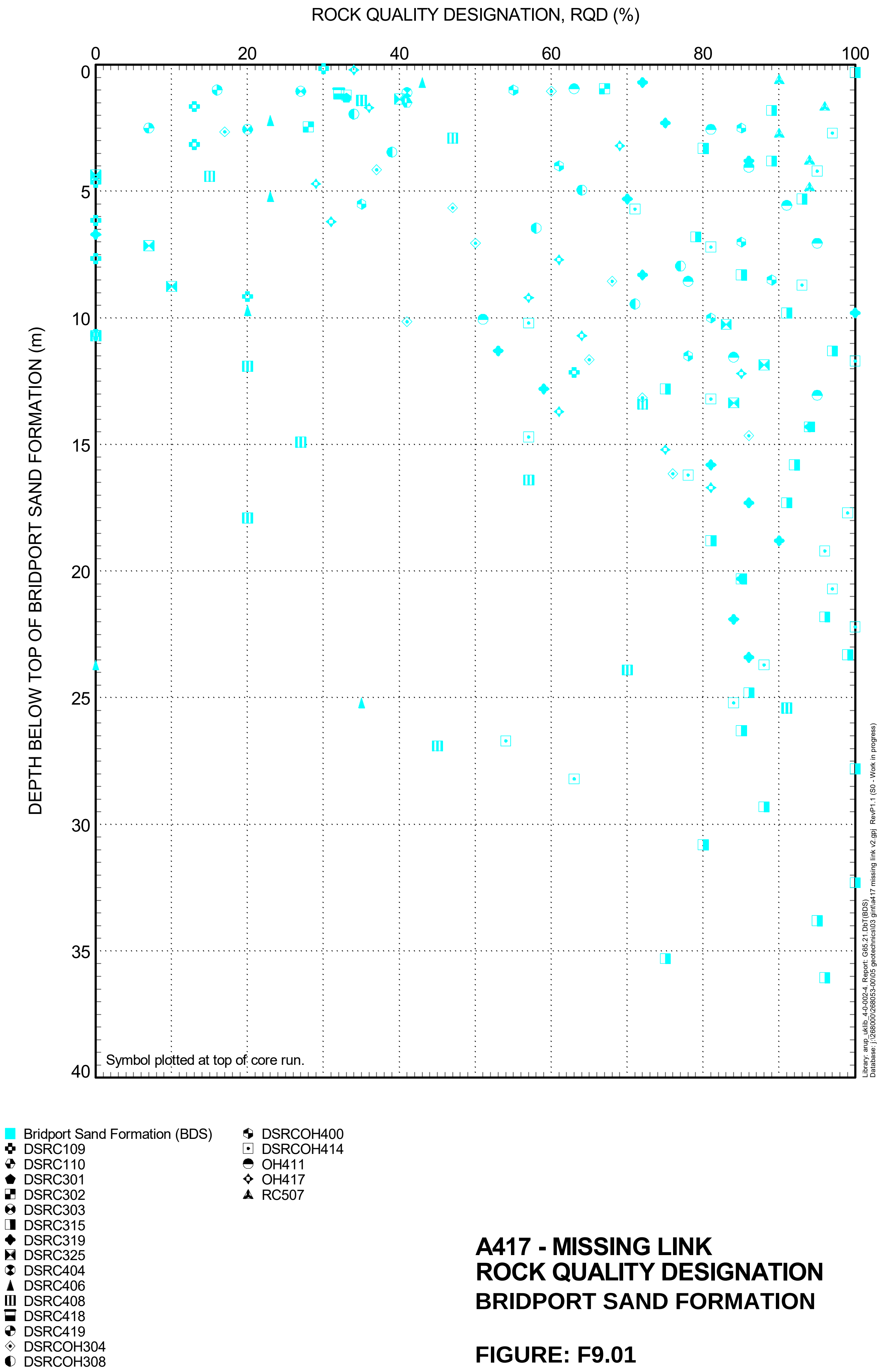
FIGURE: F8.17



A417 - MISSING LINK
SHEAR BOX TESTS
INFERIOR OOLITE GROUP

FIGURE: F8.18

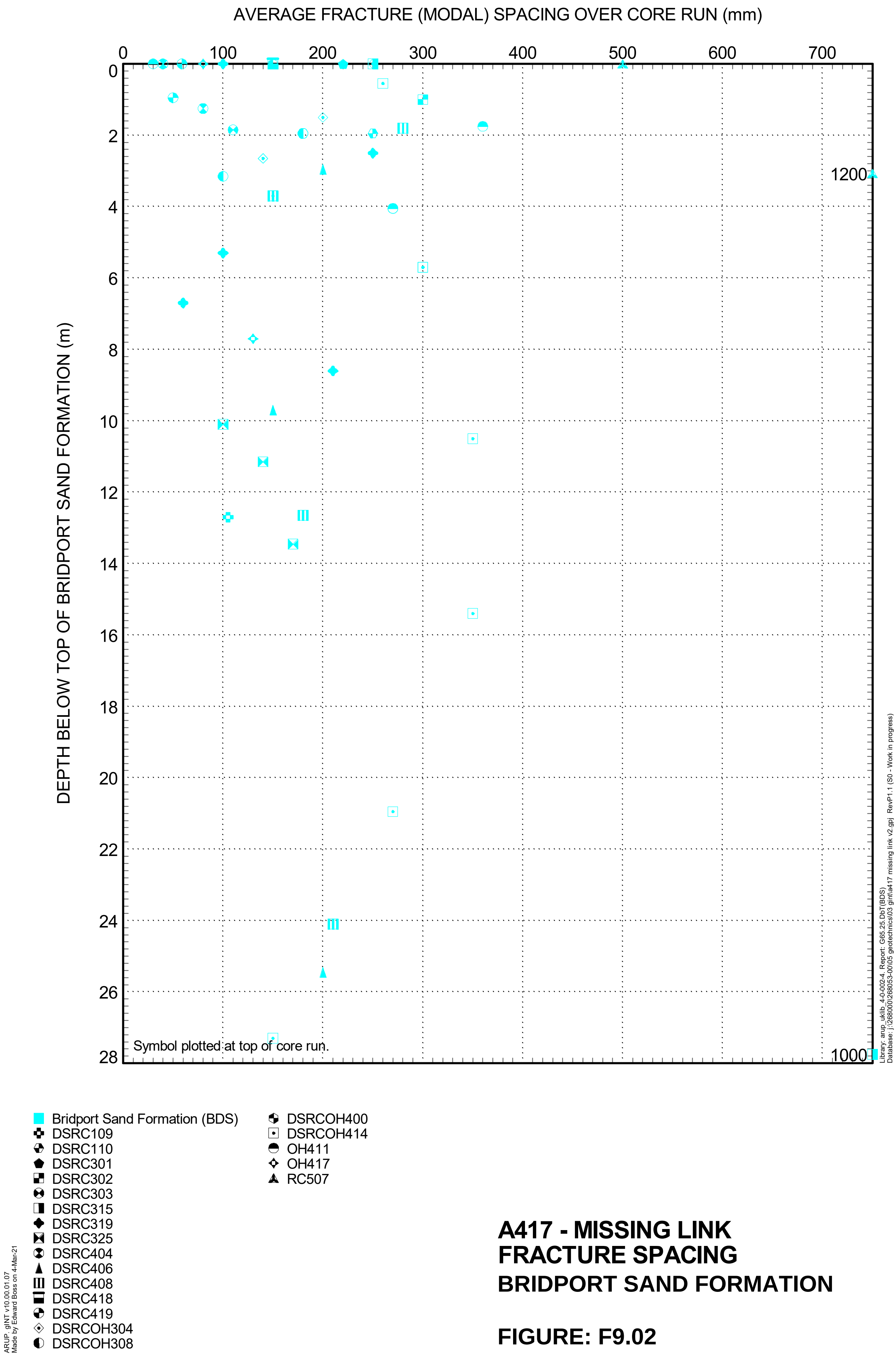
F.9 Lias Group – Bridport Sand Formation



ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ROCK QUALITY DESIGNATION
BRIDPORT SAND FORMATION

FIGURE: F9.01

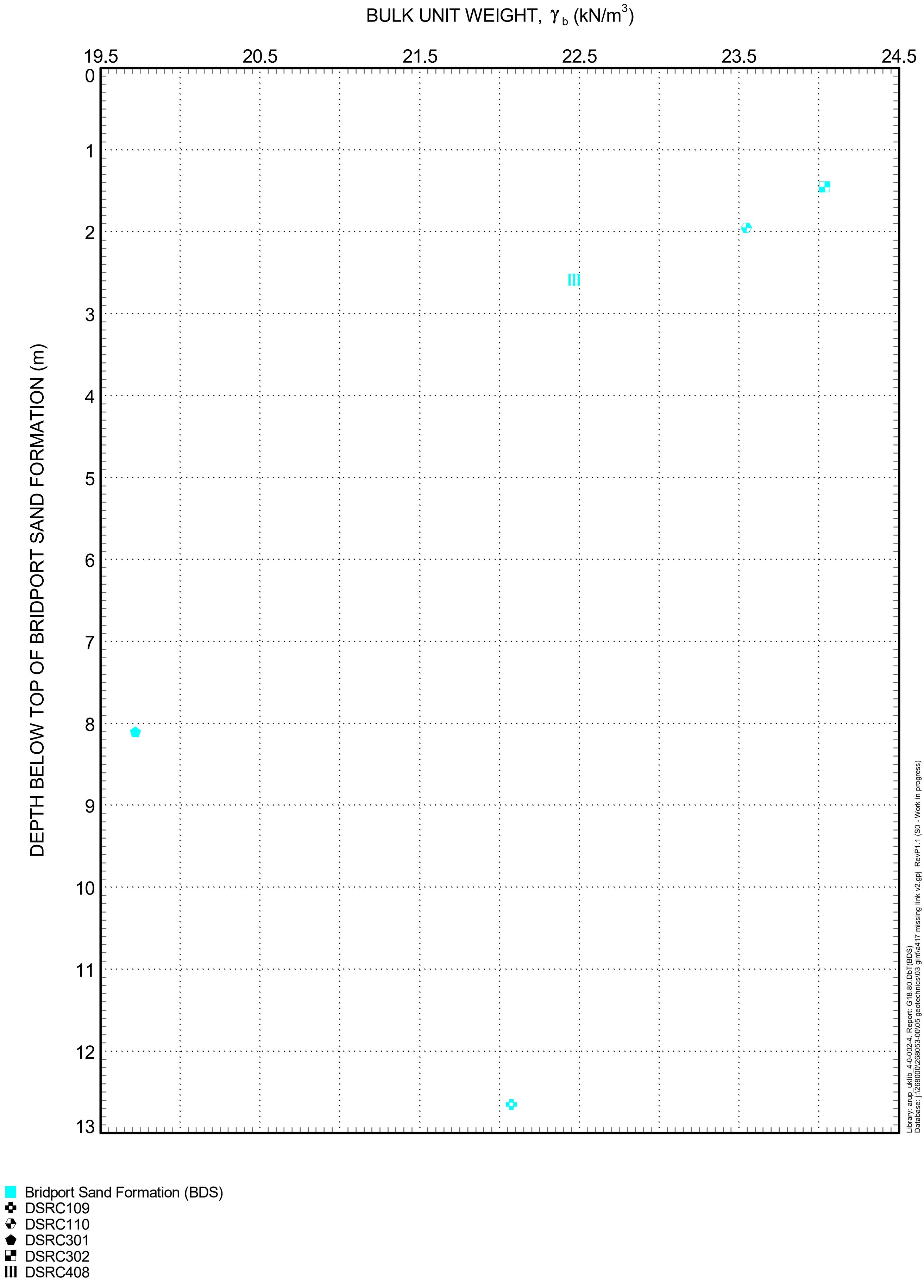


Library: arup_uklib_4-0-002-4, Report: G65.25.DbT(BDS)
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
FRACTURE SPACING
BRIDPORT SAND FORMATION

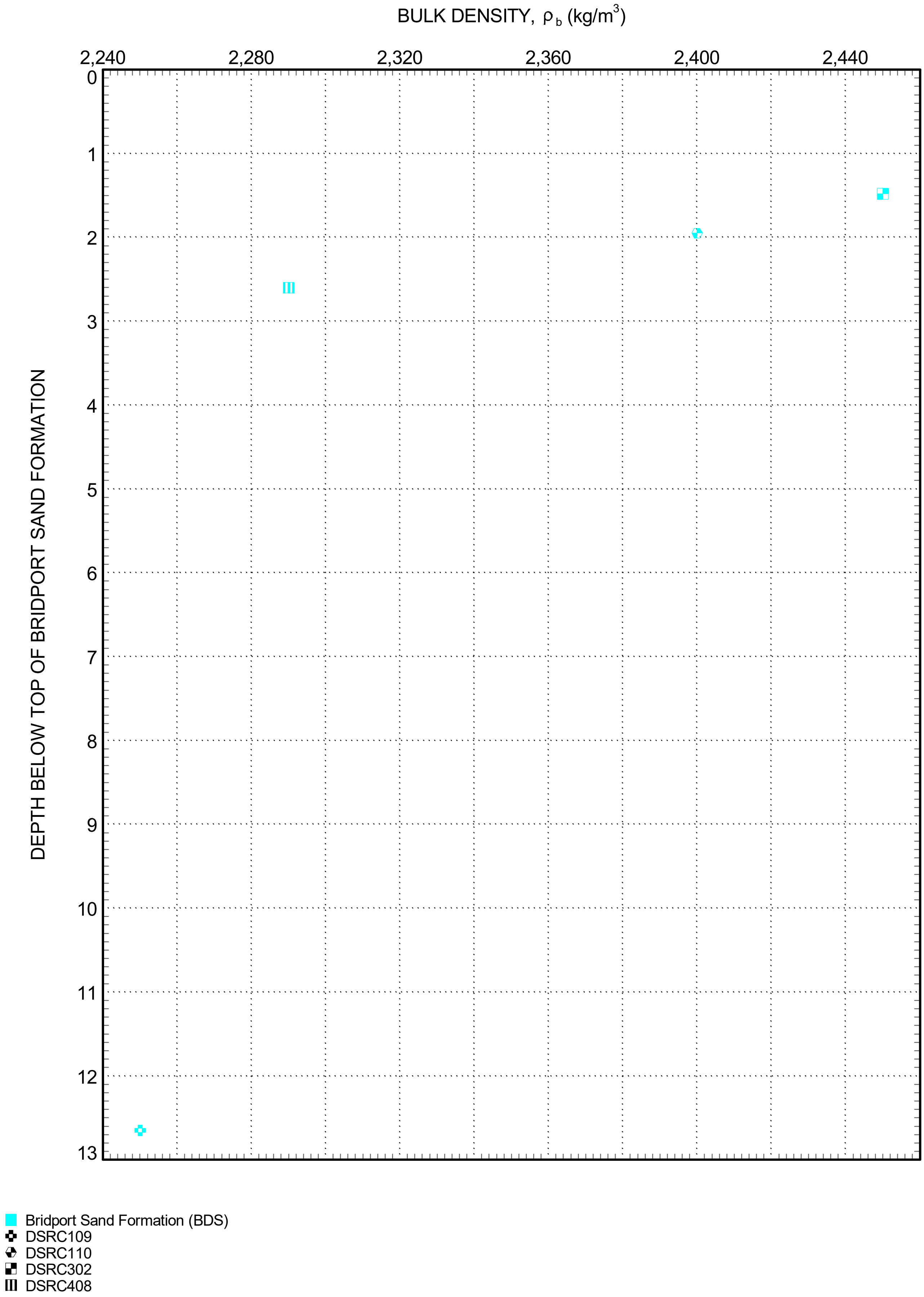
FIGURE: F9.02



A417 - MISSING LINK
BULK UNIT WEIGHT
BRIDPORT SAND FORMATION

FIGURE: F9.03

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



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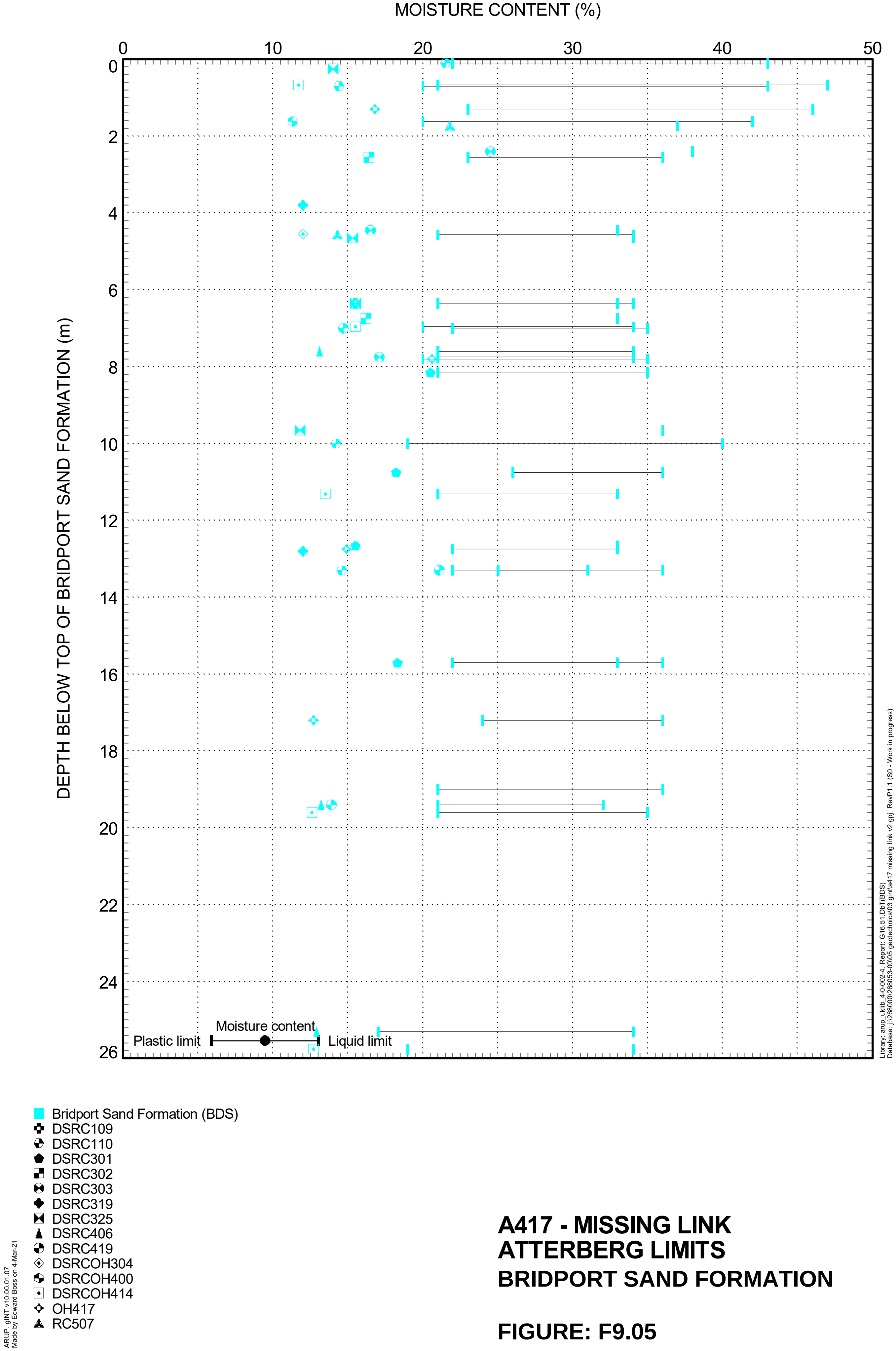
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
ROCK BULK DENSITY
BRIDPORT SAND FORMATION

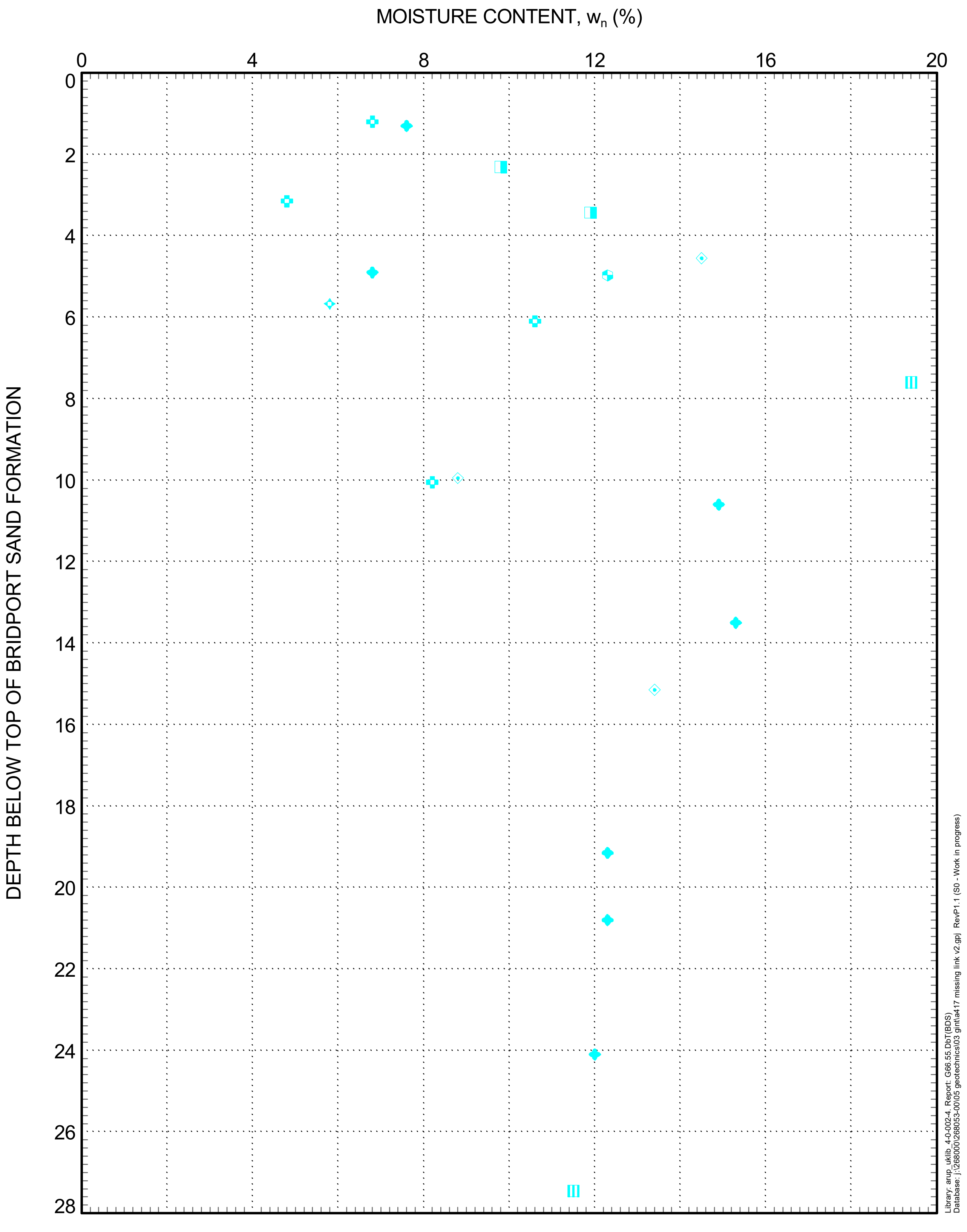
FIGURE: F9.04

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



A417 - MISSING LINK
ATTERBERG LIMITS
BRIDPORT SAND FORMATION

FIGURE: F9.05

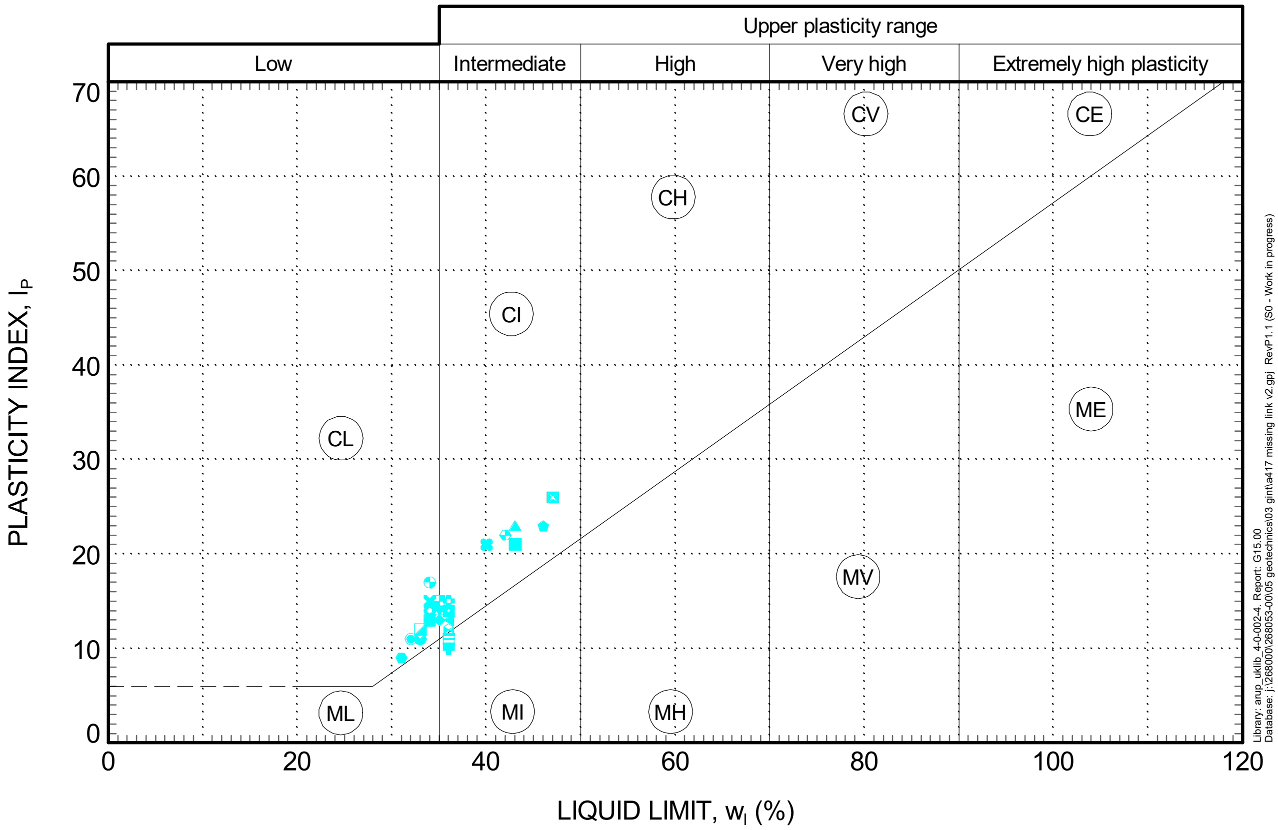


Bridport Sand Formation (BDS)
DSRC109
DSRC315
DSRC319
DSRC408
DSRCOH304
DSRCOH400
OH417

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ROCK MOISTURE CONTENT
BRIDPORT SAND FORMATION

FIGURE: F9.06



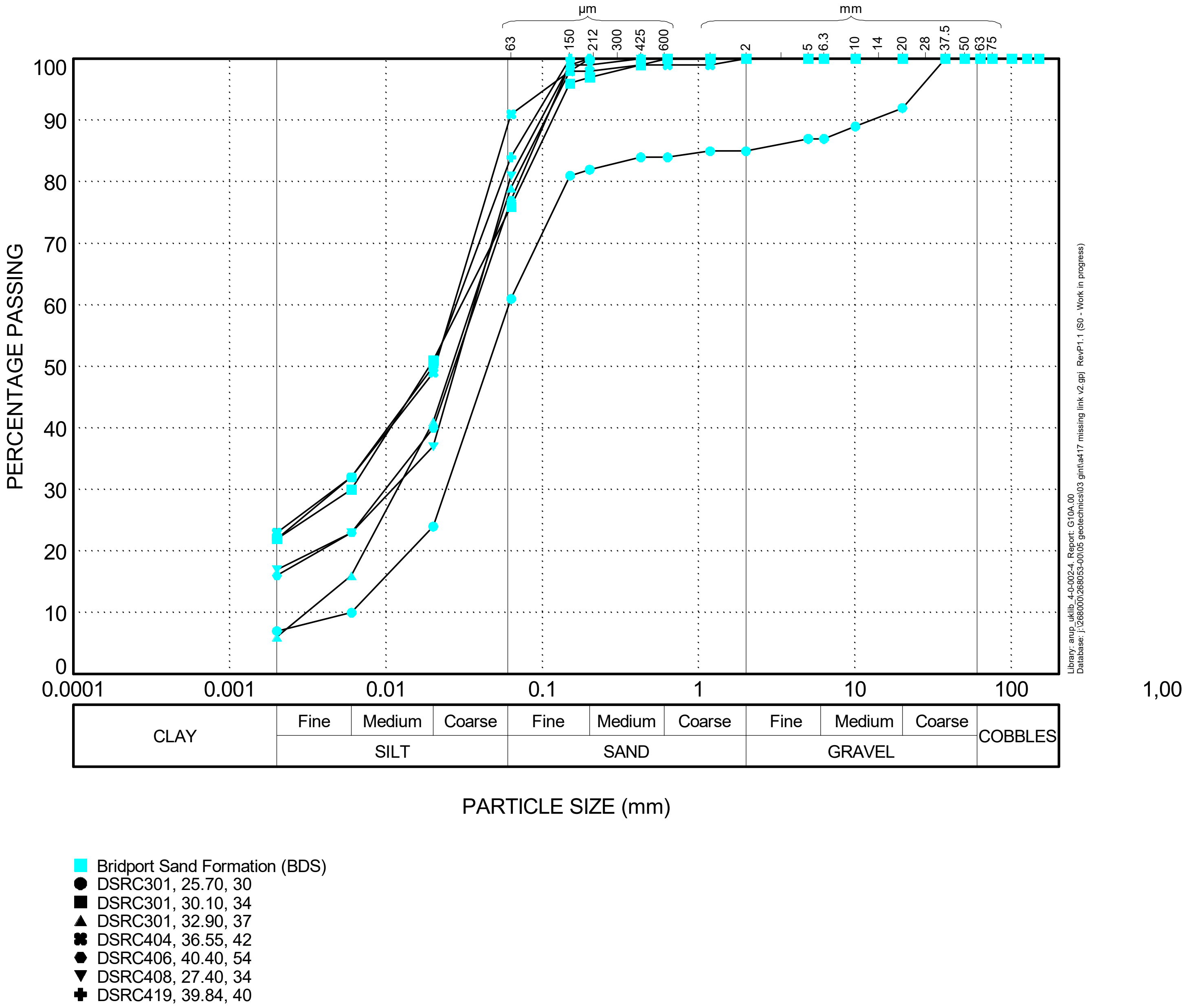
Bridport Sand Formation (BDS)
DSRC109, 27.30, 34
DSRC110, 34.80, 35
DSRC110, 35.40, 36
DSRC110, 44.70, 46
DSRC110, 48.00, 49
DSRC301, 30.55, 35
DSRC301, 33.15, 38
DSRC301, 38.10, 44
DSRC302, 29.30, 37
DSRC303, 38.70, 39
DSRC406, 41.40, 57
DSRC406, 53.20, 73
DSRC406, 59.10, 84
DSRC419, 42.10, 42
DSRC419, 48.40, 46
DSRC419, 54.10, 50
DSRCOH400, 78.92, 94
DSRCOH414, 60.97, 71
DSRCOH414, 67.26, 76
DSRCOH414, 71.61, 81
DSRCOH414, 76.00, 85
DSRCOH414, 79.90, 90
DSRCOH414, 86.06, 96
OH417, 73.10, 80
OH417, 79.60, 87
OH417, 84.55, 92
OH417, 89.00, 97
RC507, 43.75, 53

Library: arup_uklib_4-0-002-4. Report: G15.00
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
PLASTICITY CHART
BRIDPORT SAND FORMATION

FIGURE: F9.07

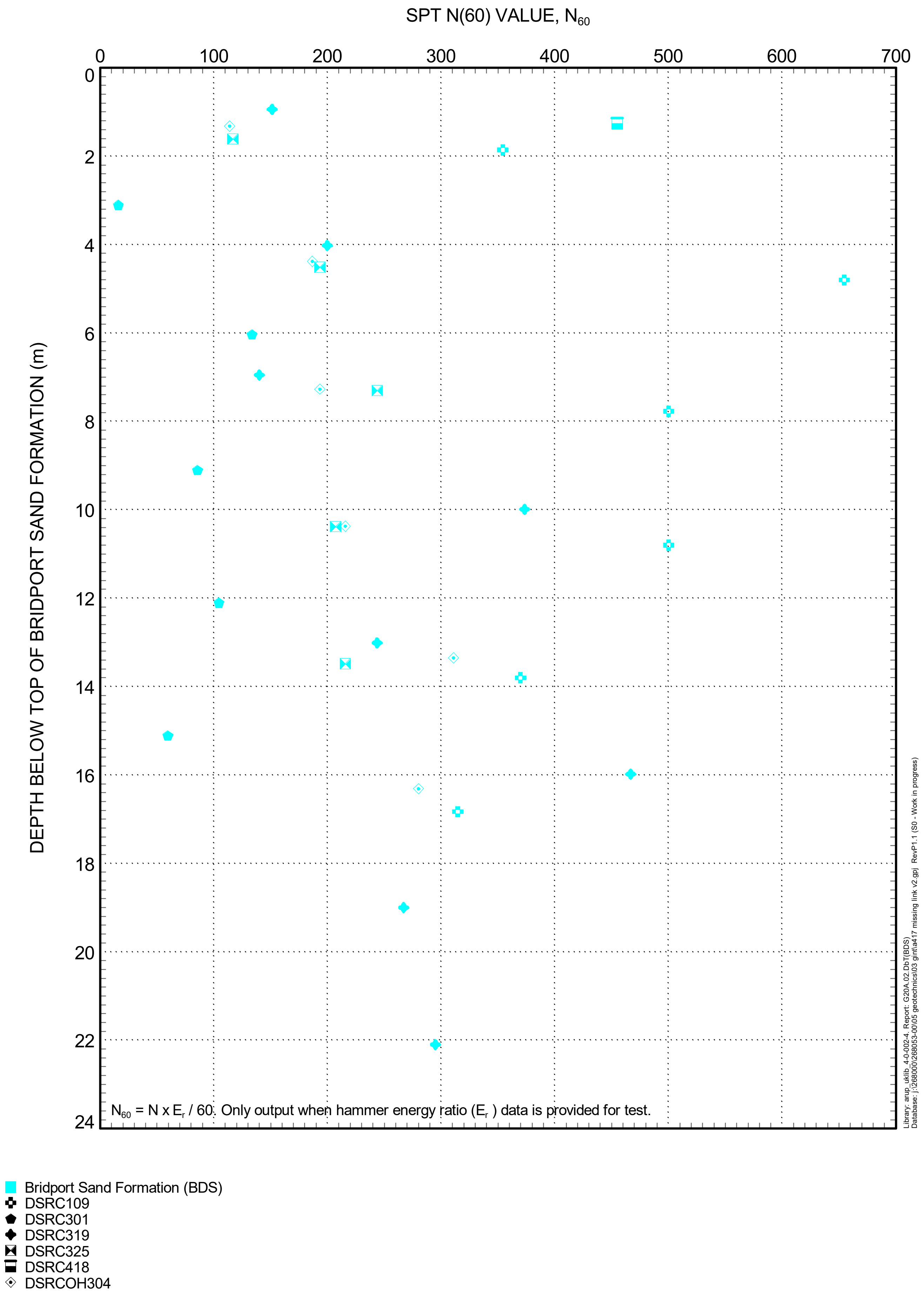
ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
PARTICLE SIZE DISTRIBUTION
BRIDPORT SAND FORMATION

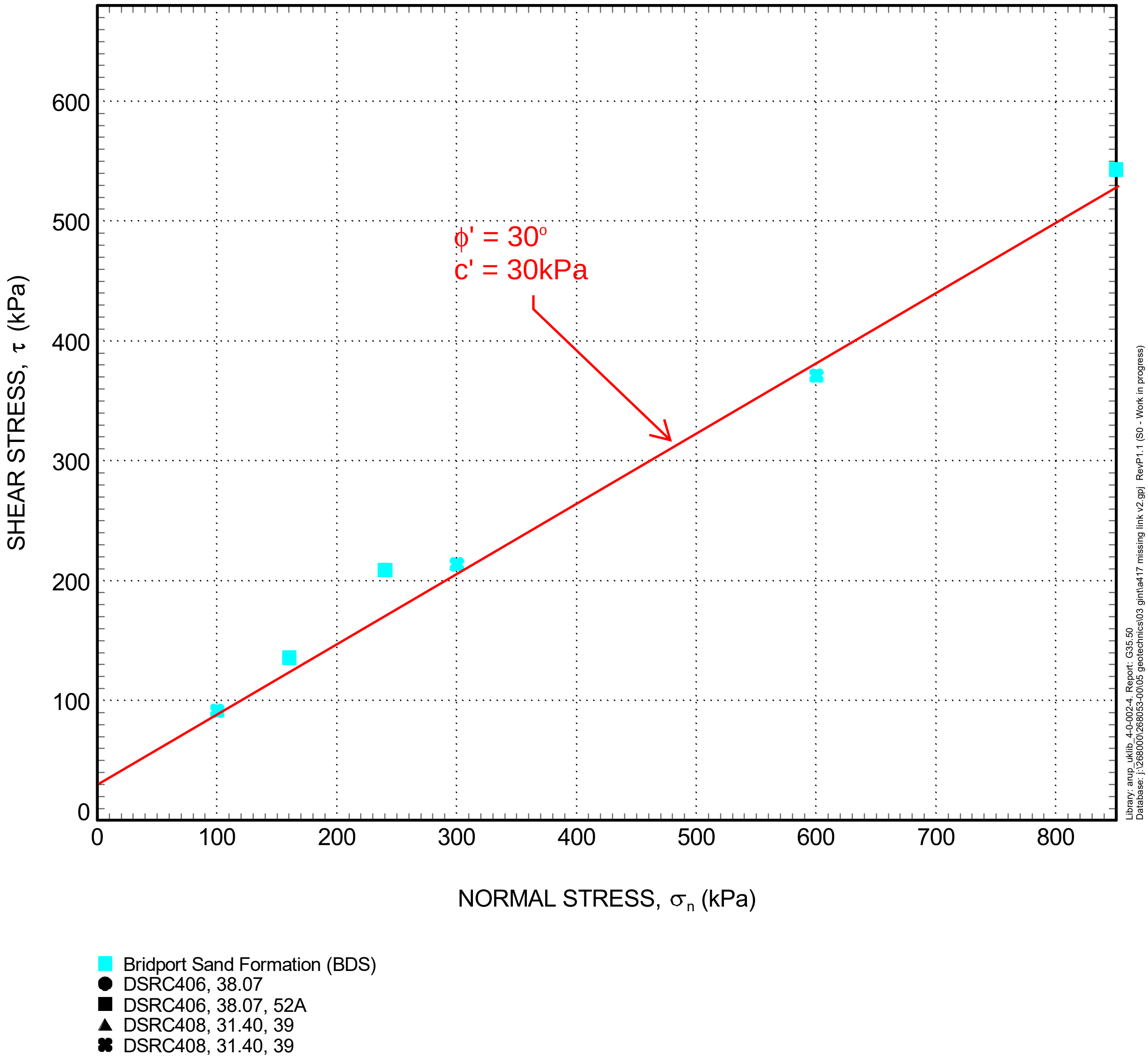
FIGURE: F9.08



A417 - MISSING LINK
STANDARD PENETRATION TESTS
BRIDPORT SAND FORMATION

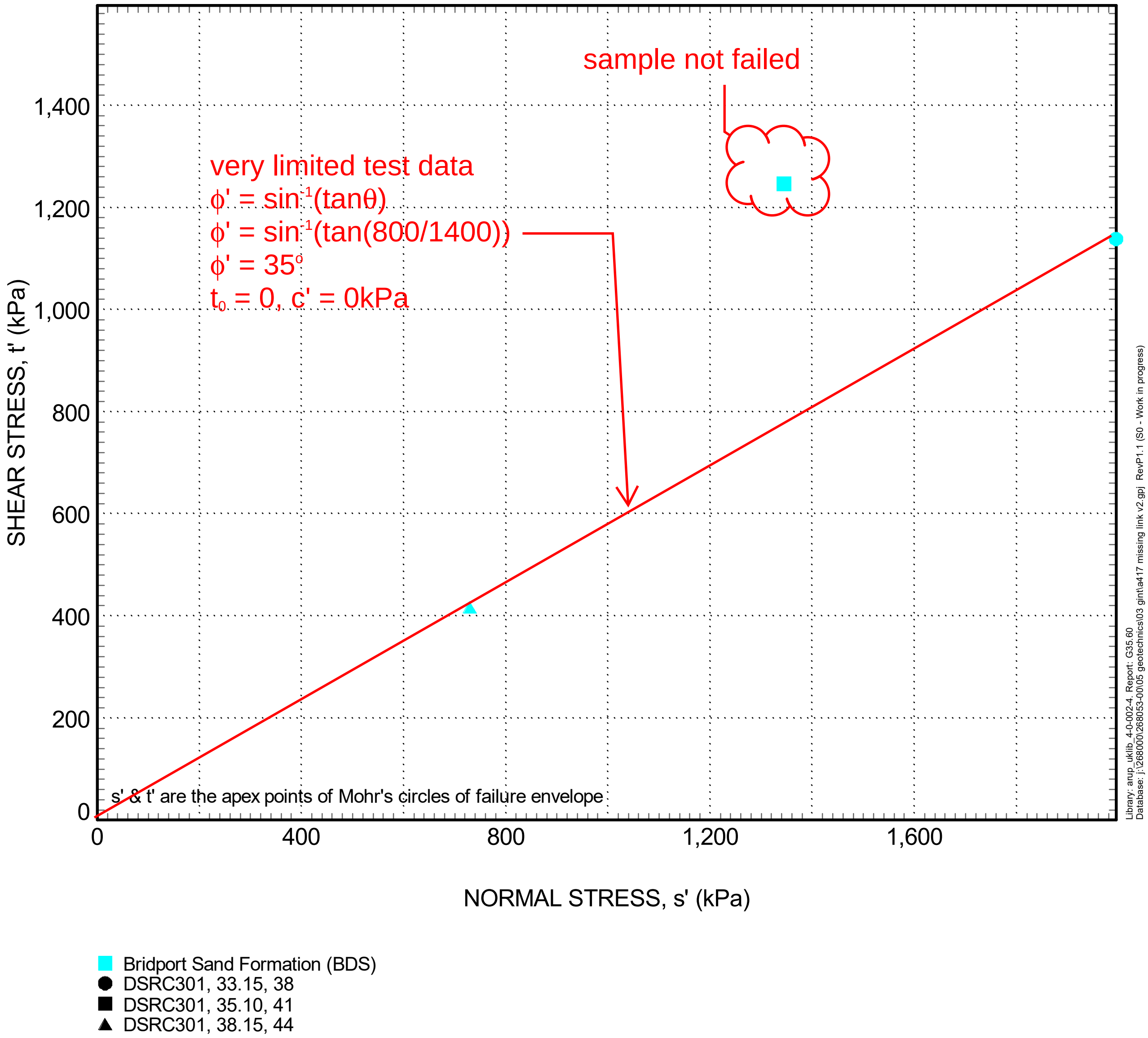
FIGURE: F9.09

Library: arup_uklib_4-0-002-4, Report: G20A.02 DbT(BDS)
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)
ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



A417 - MISSING LINK
SHEAR BOX TESTS
BRIDPORT SAND FORMATION

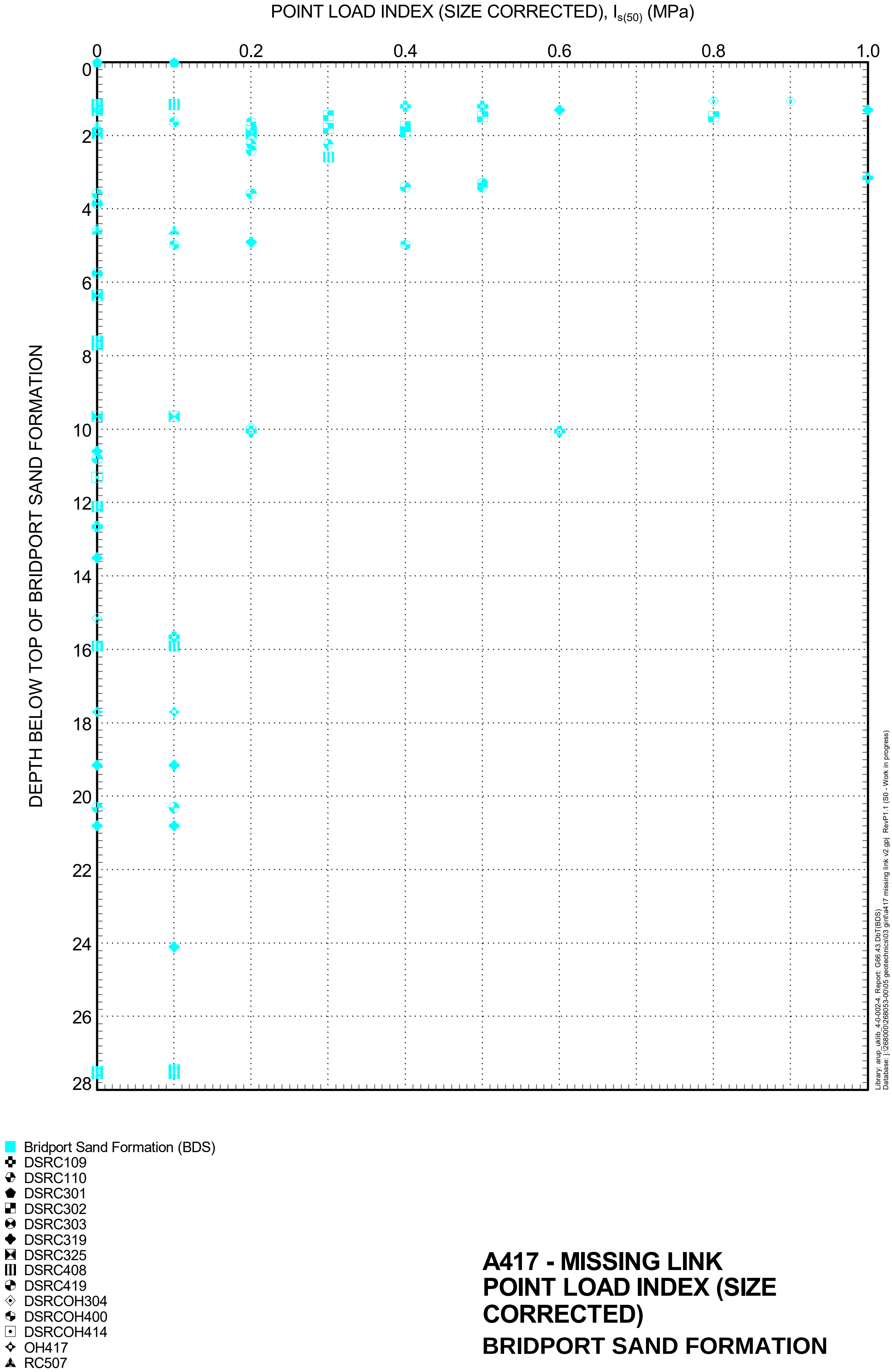
FIGURE: F9.10



A417 - MISSING LINK
TRIAXIAL T' V S'
BRIDPORT SAND FORMATION

FIGURE: F9.11

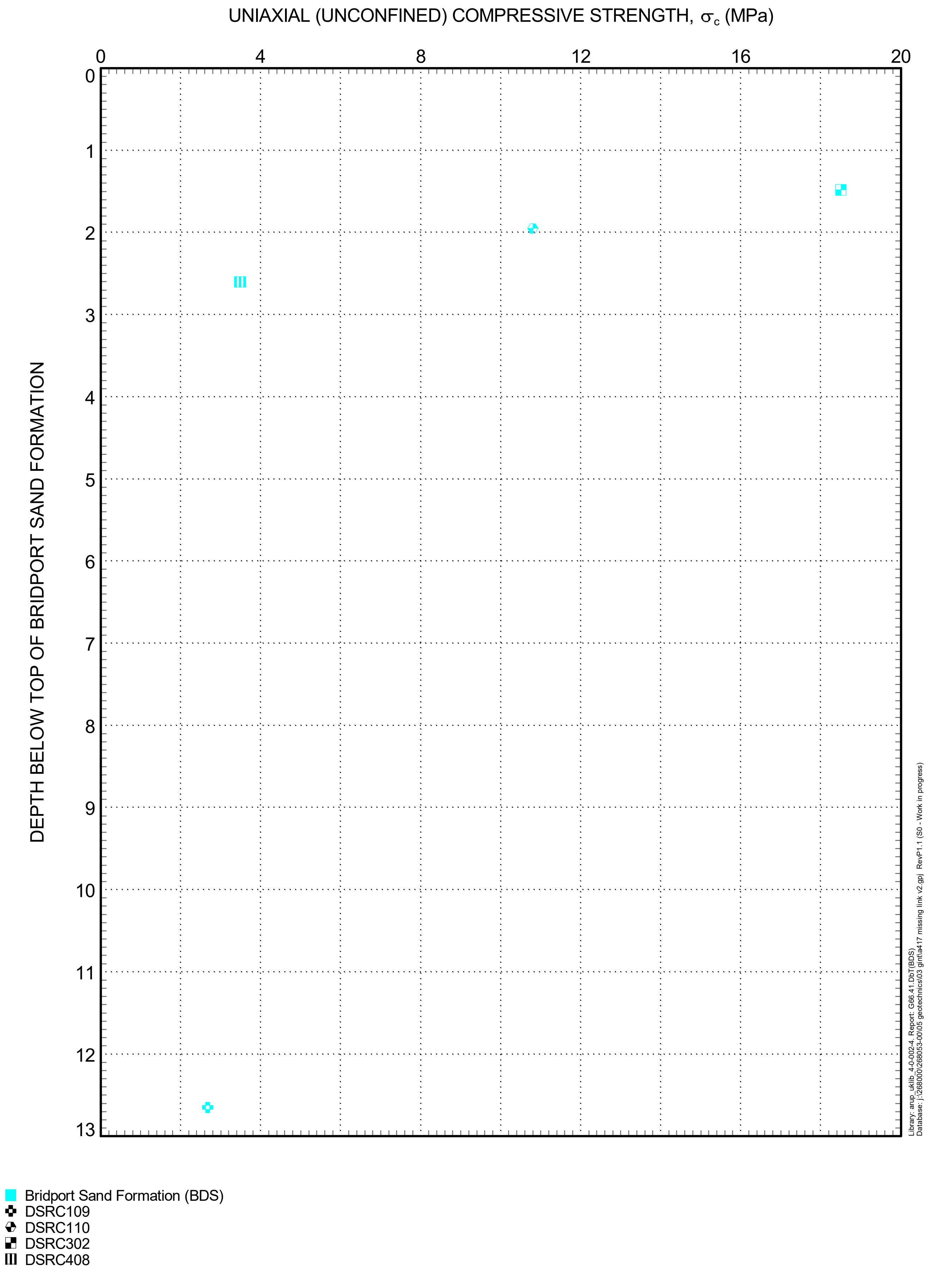
ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
POINT LOAD INDEX (SIZE CORRECTED)
BRIDPORT SAND FORMATION

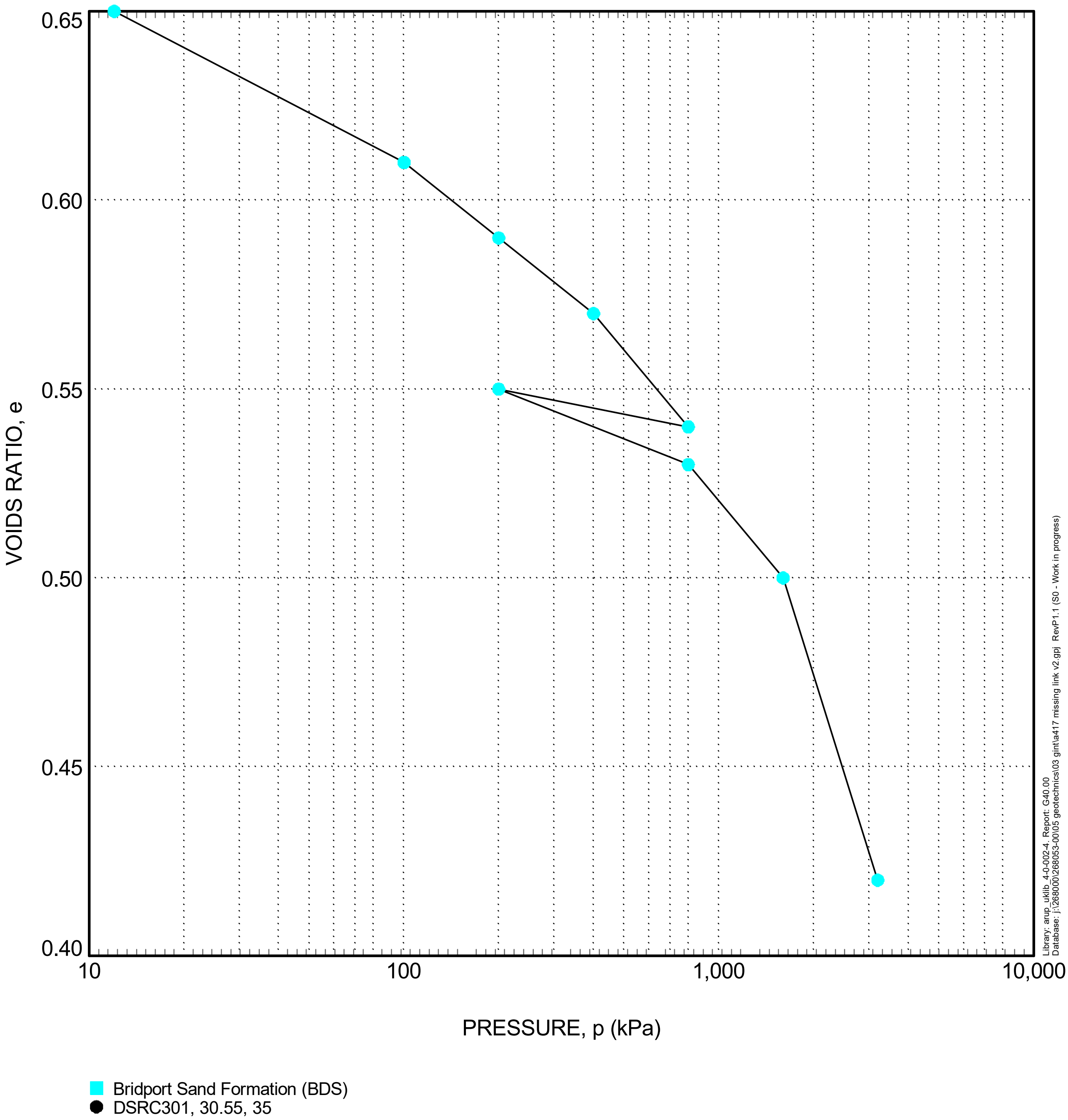
FIGURE: F9.12



A417 - MISSING LINK
UNIAXIAL COMPRESSIVE STRENGTH
BRIDPORT SAND FORMATION

FIGURE: F9.13

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



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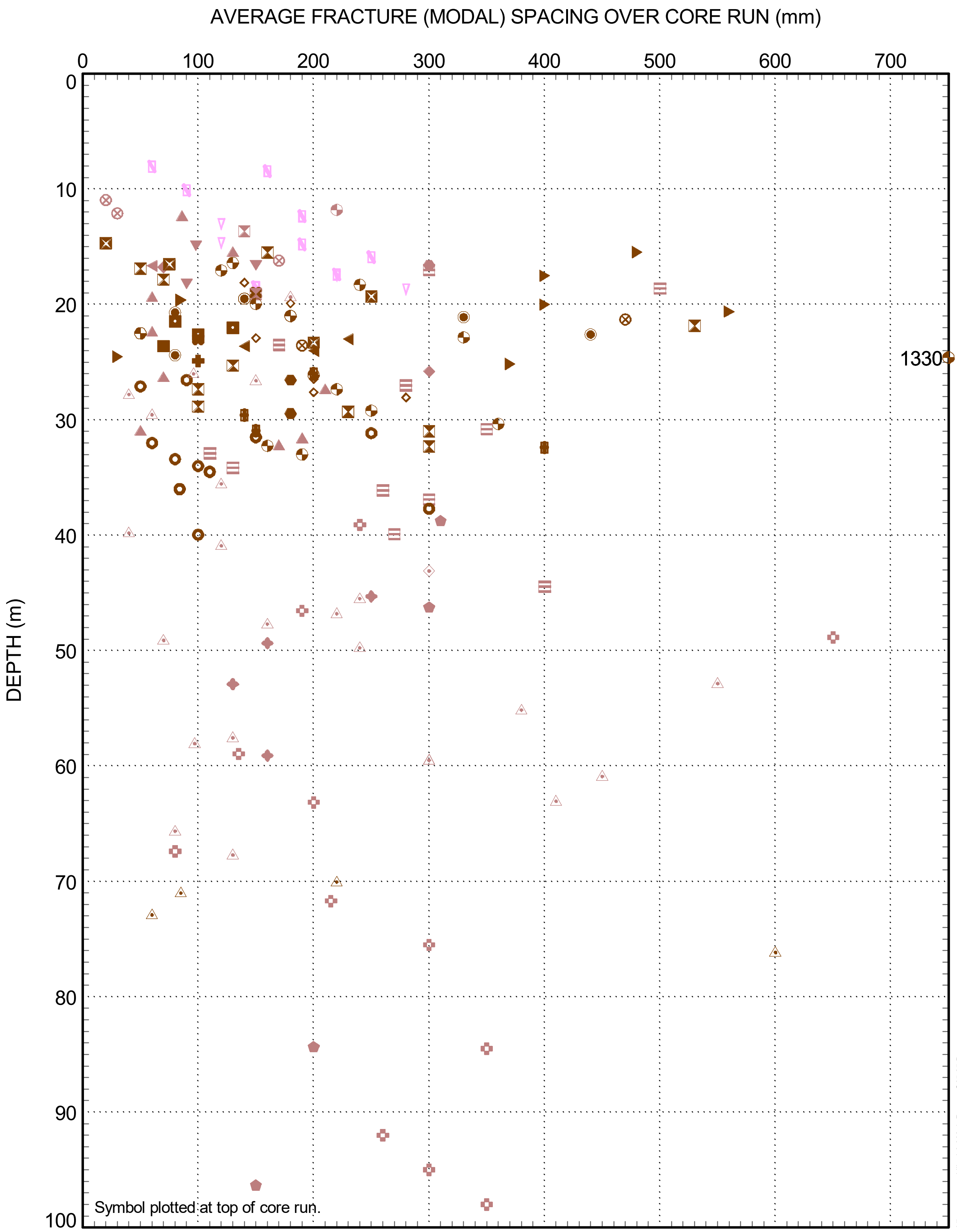
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
CONSOLIDATION TESTS
BRIDPORT SAND FORMATION

FIGURE: F9.14

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

F.10 Lias Group – mudstones



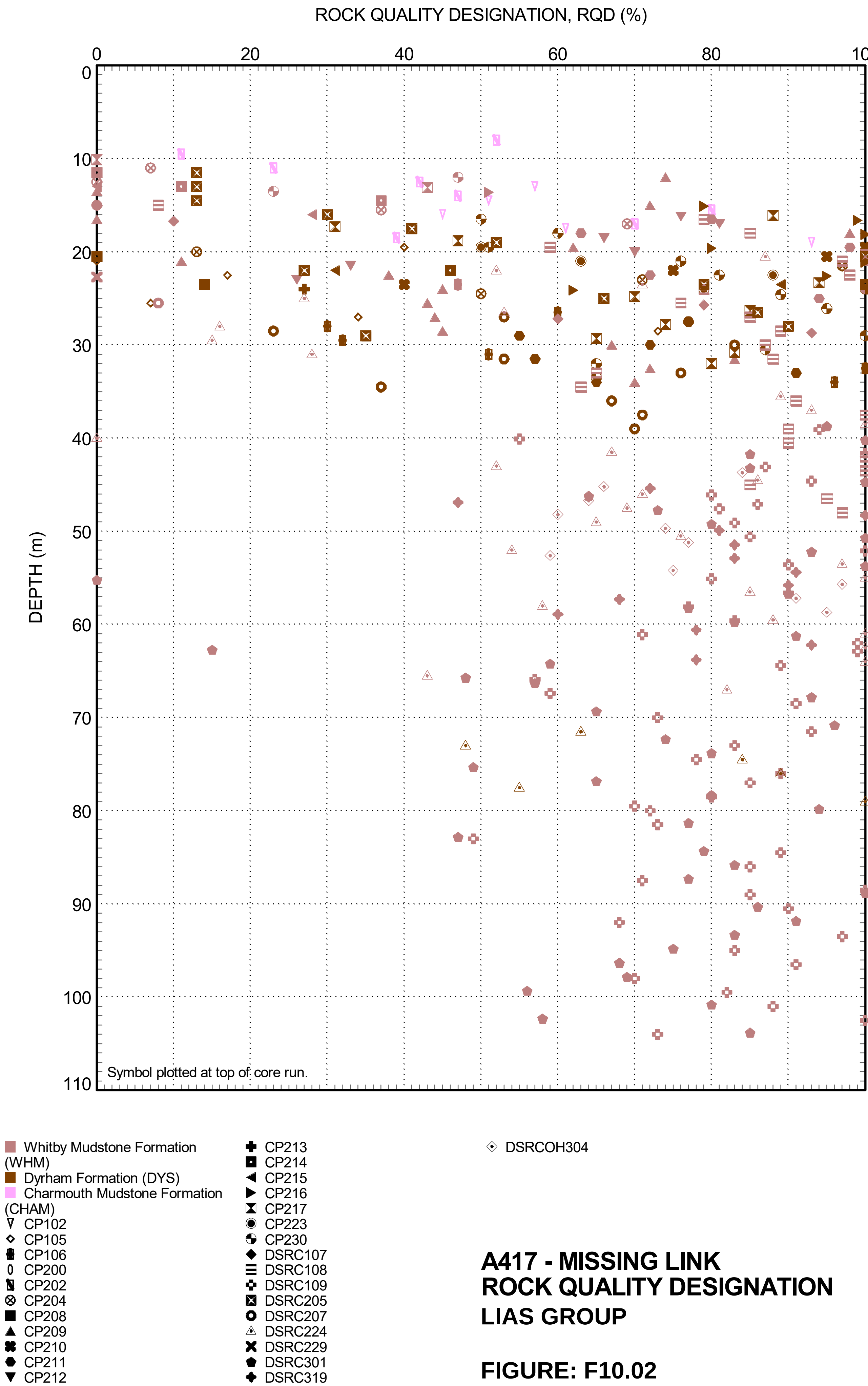
- Whitby Mudstone Formation (WHM)
- Dyrham Formation (DYS)
- Charmouth Mudstone Formation (CHAM)
- CP102
- CP105
- CP106
- CP202
- CP204
- CP208
- CP209
- CP210
- CP211
- CP212
- CP213
- CP214
- CP215
- CP216
- CP217
- CP223
- CP230
- DSRC107
- DSRC108
- DSRC109
- DSRC205
- DSRC207
- DSRC224
- DSRC301
- DSRC319
- DSRCOH304

A417 - MISSING LINK
FRACTURE SPACING
LIAS GROUP

FIGURE: F10.01

Library: arup_uklib_4-0-002-4, Report: G65.25.D RevP1.1 (S0 - Work in progress)
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



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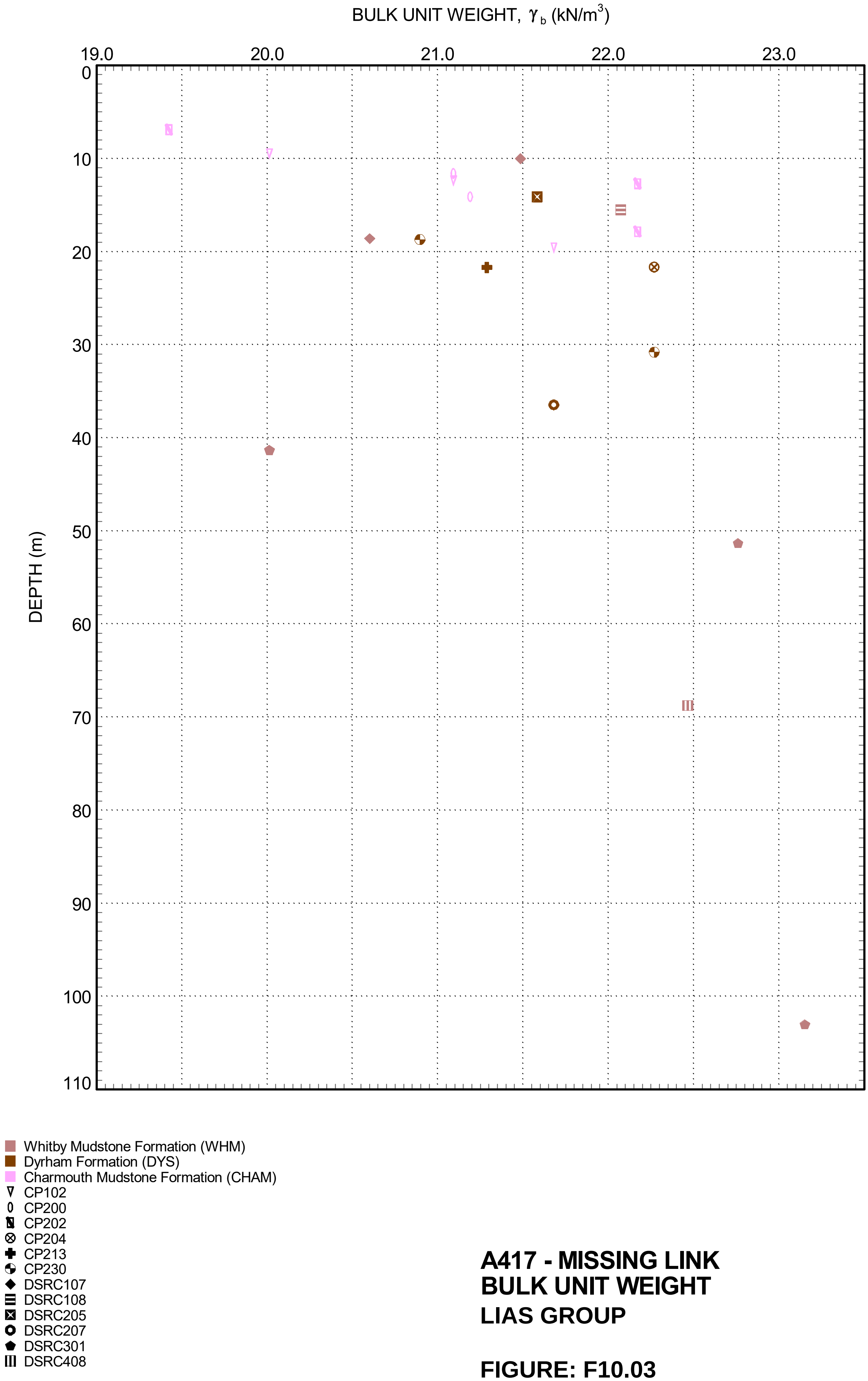
ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ROCK QUALITY DESIGNATION
LIAS GROUP

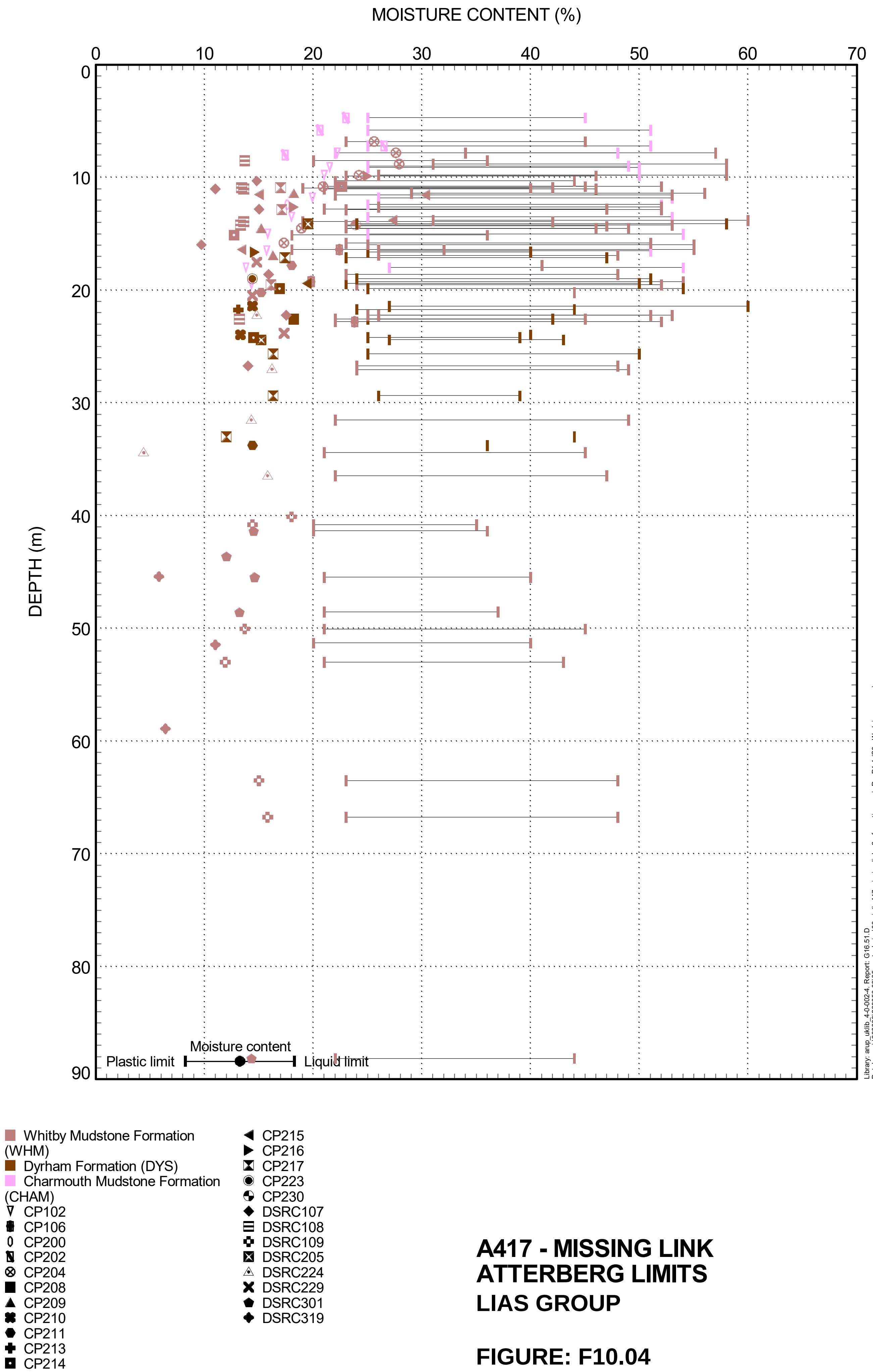
FIGURE: F10.02



A417 - MISSING LINK
BULK UNIT WEIGHT
LIAS GROUP

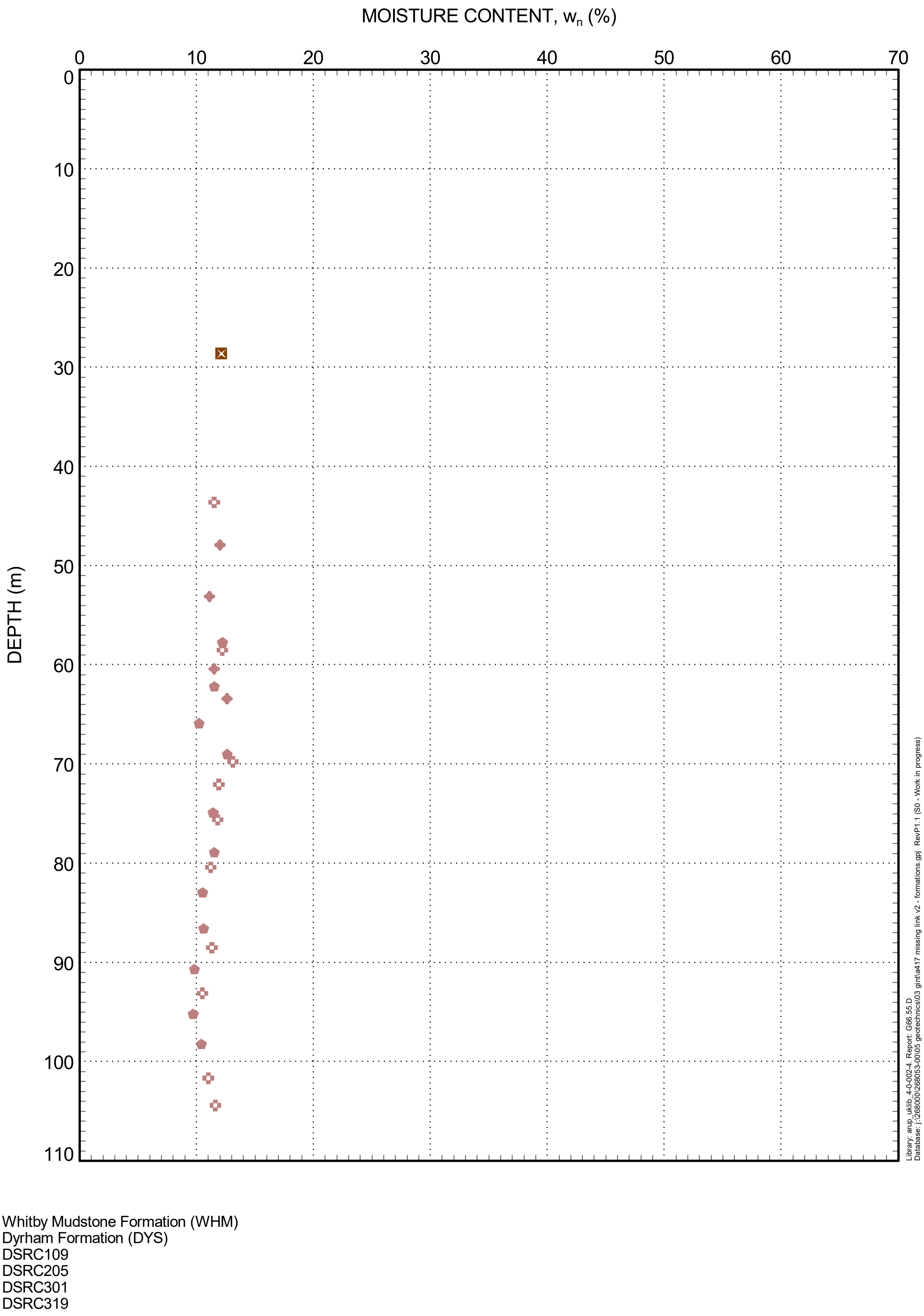
FIGURE: F10.03

ARUP, gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



A417 - MISSING LINK
ATTERBERG LIMITS
LIAS GROUP

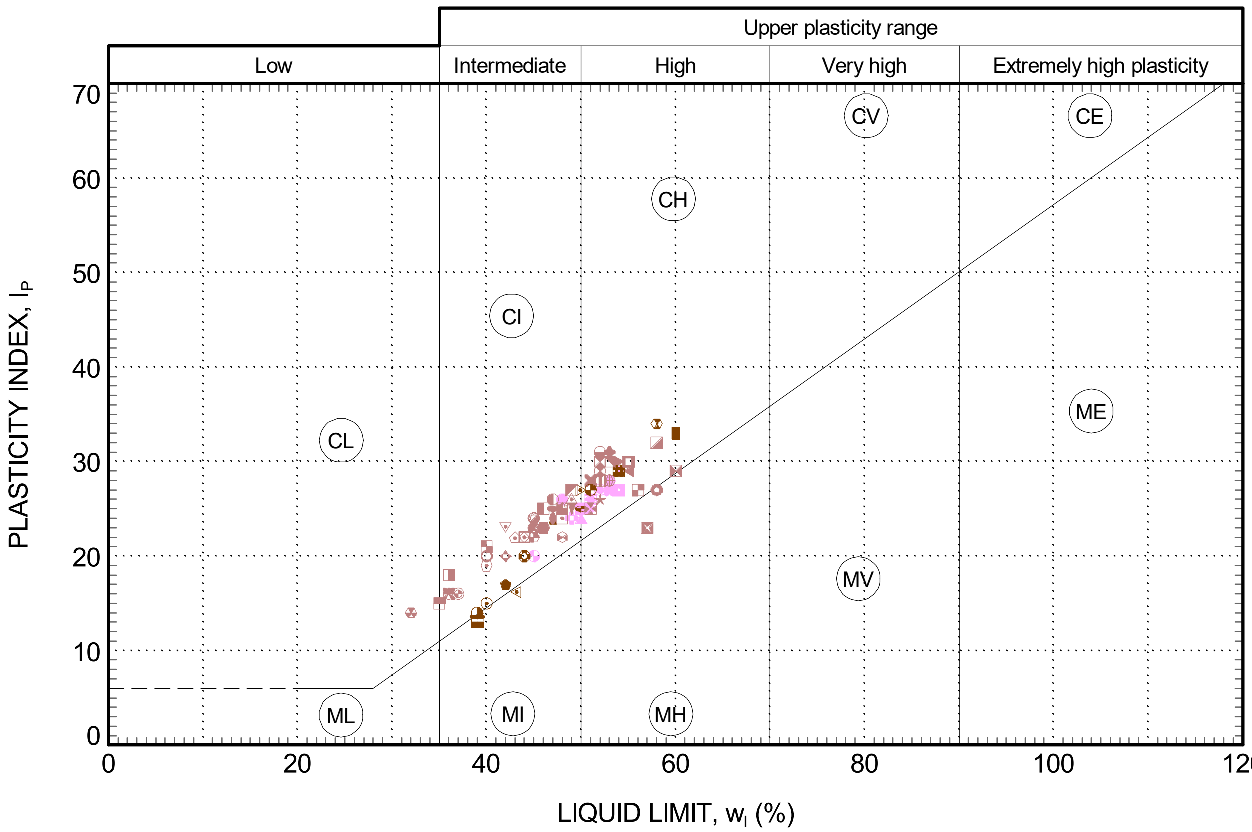
FIGURE: F10.04



ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
ROCK MOISTURE CONTENT
LIAS GROUP

FIGURE: F10.05



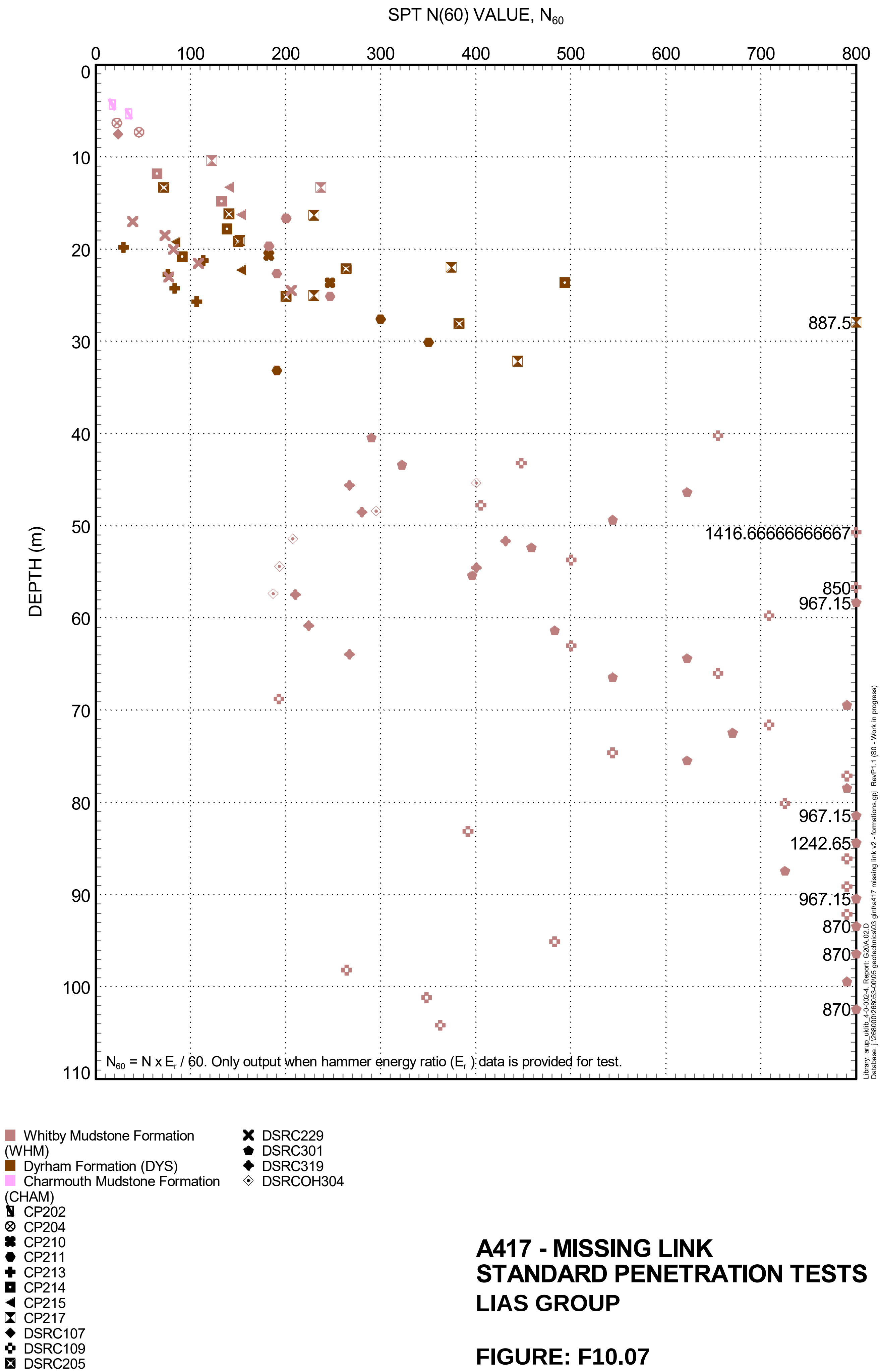
- Whitby Mudstone Formation (WHM)
- Dyrham Formation (DYS)
- Charmouth Mudstone Formation (CHAM)
- CP102, 7.80m, 24
- CP102, 9.10m, 26
- CP102, 9.80m, 28
- CP102, 11.80m, 32
- CP102, 13.50m, 34
- CP102, 15.00m, 35
- CP102, 16.50m, 36
- CP102, 18.00m, 37
- CP106, 16.40m, 44
- CP106, 19.25m, 50
- CP106, 22.80m, 57
- CP200, 12.40m, 34
- CP202, 4.70m, 18
- CP202, 5.80m, 21
- CP202, 7.20m, 24
- CP202, 9.00m, 26
- CP204, 6.80m, 24
- CP204, 7.80m, 27
- CP204, 8.80m, 29
- CP204, 9.80m, 31
- CP204, 10.80m, 32
- CP204, 14.50m, 37
- CP204, 15.80m, 40
- CP208, 22.55m, 41
- CP209, 11.40m, 21
- CP209, 14.50m, 25
- CP209, 16.90m, 28
- CP210, 21.40m, 34
- CP213, 21.70m, 56
- CP214, 10.80m, 31
- CP214, 15.10m, 40
- CP214, 19.85m, 49
- CP214, 24.20m, 54
- CP215, 11.55m, 42
- CP215, 13.80m, 47
- CP215, 16.40m, 52
- CP215, 19.40m, 56
- CP216, 9.85m, 27
- CP216, 12.60m, 31
- CP216, 16.60m, 36
- CP217, 10.95m, 32
- CP217, 12.85m, 34
- CP217, 17.10m, 38
- CP217, 19.50m, 41
- CP217, 25.65m, 47
- CP217, 29.35m, 53
- CP223, 18.98m, 34
- CP230, 14.20m, 26
- DSRC107, 10.30m, 31
- DSRC107, 12.80m, 35
- DSRC107, 15.95m, 40
- DSRC107, 18.60m, 45
- DSRC107, 22.20m, 51
- DSRC107, 26.70m, 57
- DSRC108, 8.50m, 24
- DSRC108, 11.00m, 29
- DSRC108, 10.90m, 30
- DSRC108, 13.90m, 35
- DSRC108, 14.30m, 36
- DSRC108, 22.55m, 46
- DSRC109, 40.80m, 47
- DSRC109, 50.05m, 58
- DSRC109, 53.00m, 61
- DSRC109, 63.50m, 72
- DSRC109, 66.75m, 75
- DSRC205, 14.10m, 37
- DSRC205, 24.40m, 49
- DSRC224, 22.20m, 45
- DSRC224, 27.05m, 49
- DSRC224, 31.50m, 53
- DSRC224, 34.40m, 55
- DSRC224, 36.45m, 57
- DSRC301, 41.35m, 47
- DSRC301, 45.45m, 52
- DSRC301, 48.55m, 55
- DSRC301, 51.30m, 58
- DSRC301, 88.15m, 98

A417 - MISSING LINK
PLASTICITY CHART
LIAS GROUP

FIGURE: F10.06

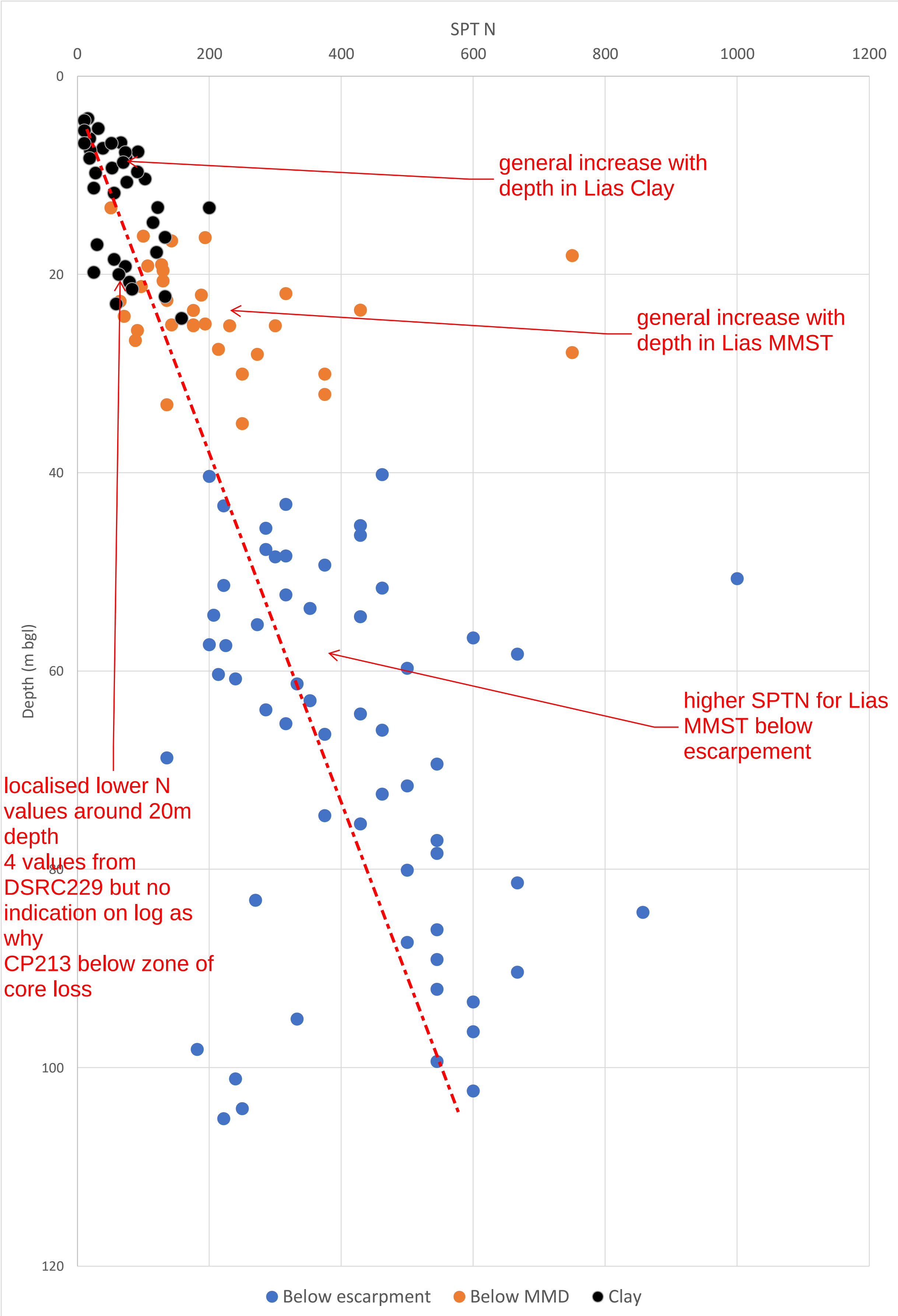
Library: arup_uklib_4-0-002-4, Report: G15.00
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



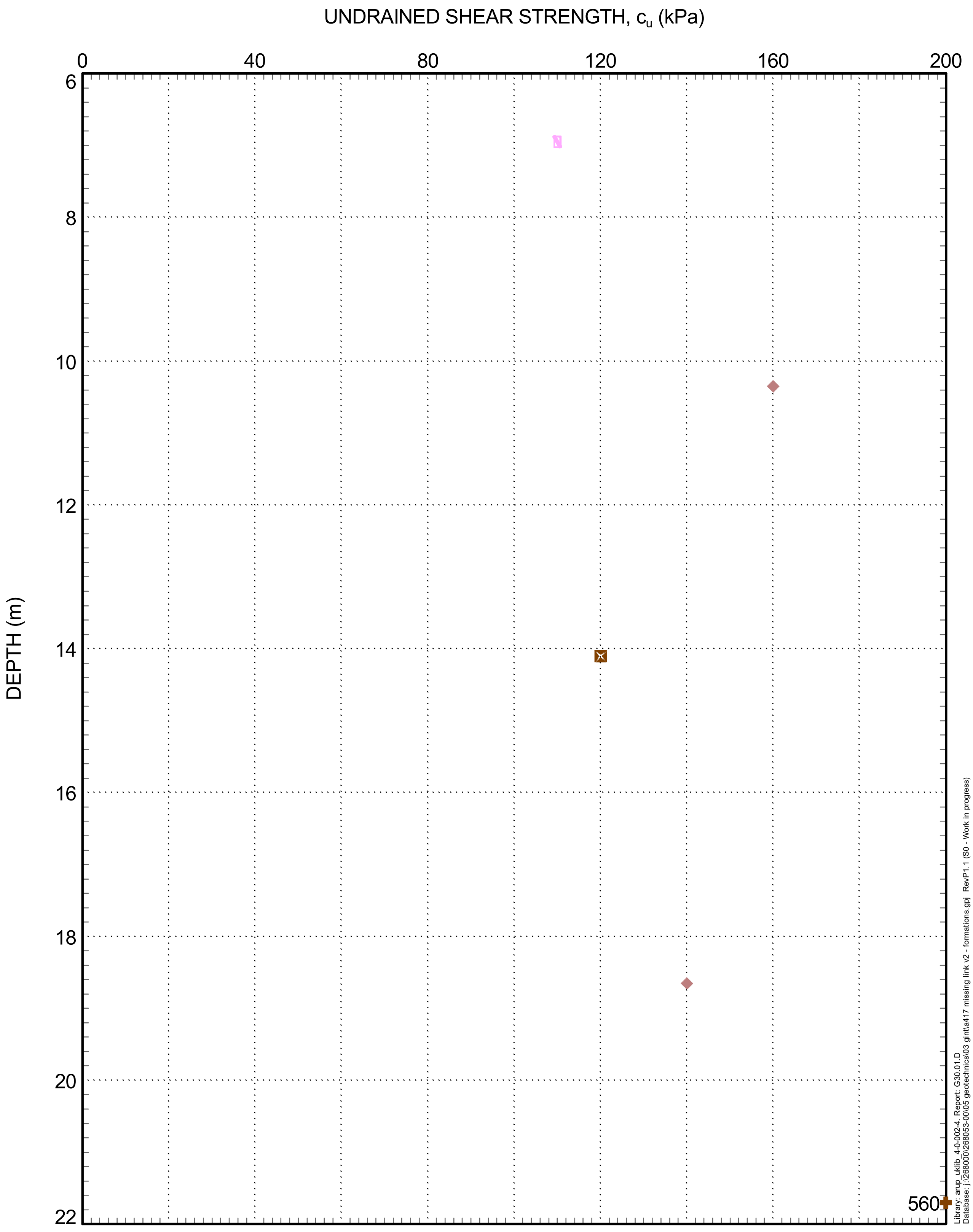
A417 - MISSING LINK
STANDARD PENETRATION TESTS
LIAS GROUP

FIGURE: F10.07



A417 MISSING LINK
STANDARD PENETRATION TEST WITH DEPTH
LIAS GROUP

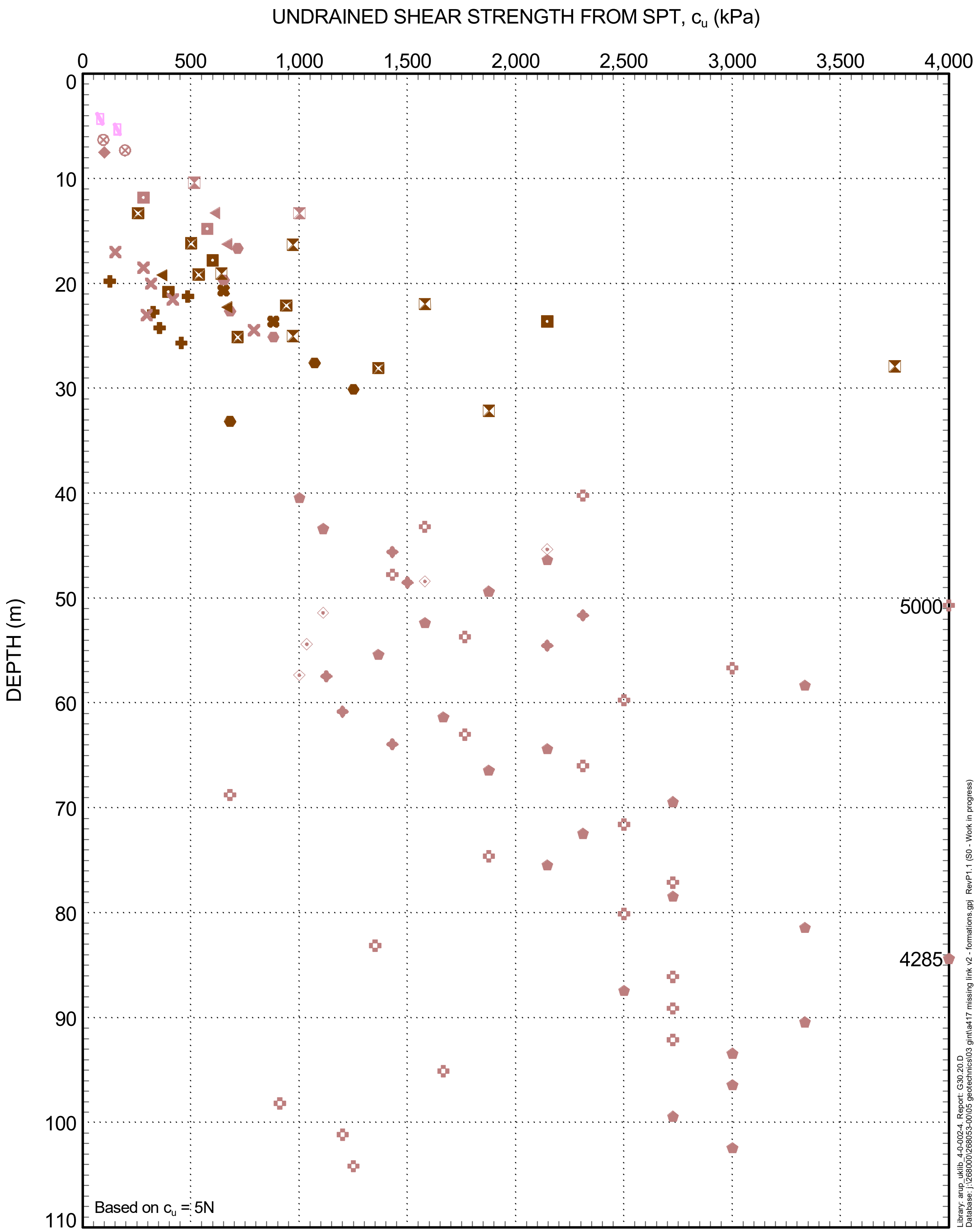
FIGURE: F10.08



Whitby Mudstone Formation (WHM)
Dyrham Formation (DYS)
Charmouth Mudstone Formation (CHAM)
CP202
CP213
DSRC107
DSRC205

A417 - MISSING LINK
TRIAXIAL UNDRAINED SHEAR STRENGTH
LIAS GROUP

FIGURE: F10.09



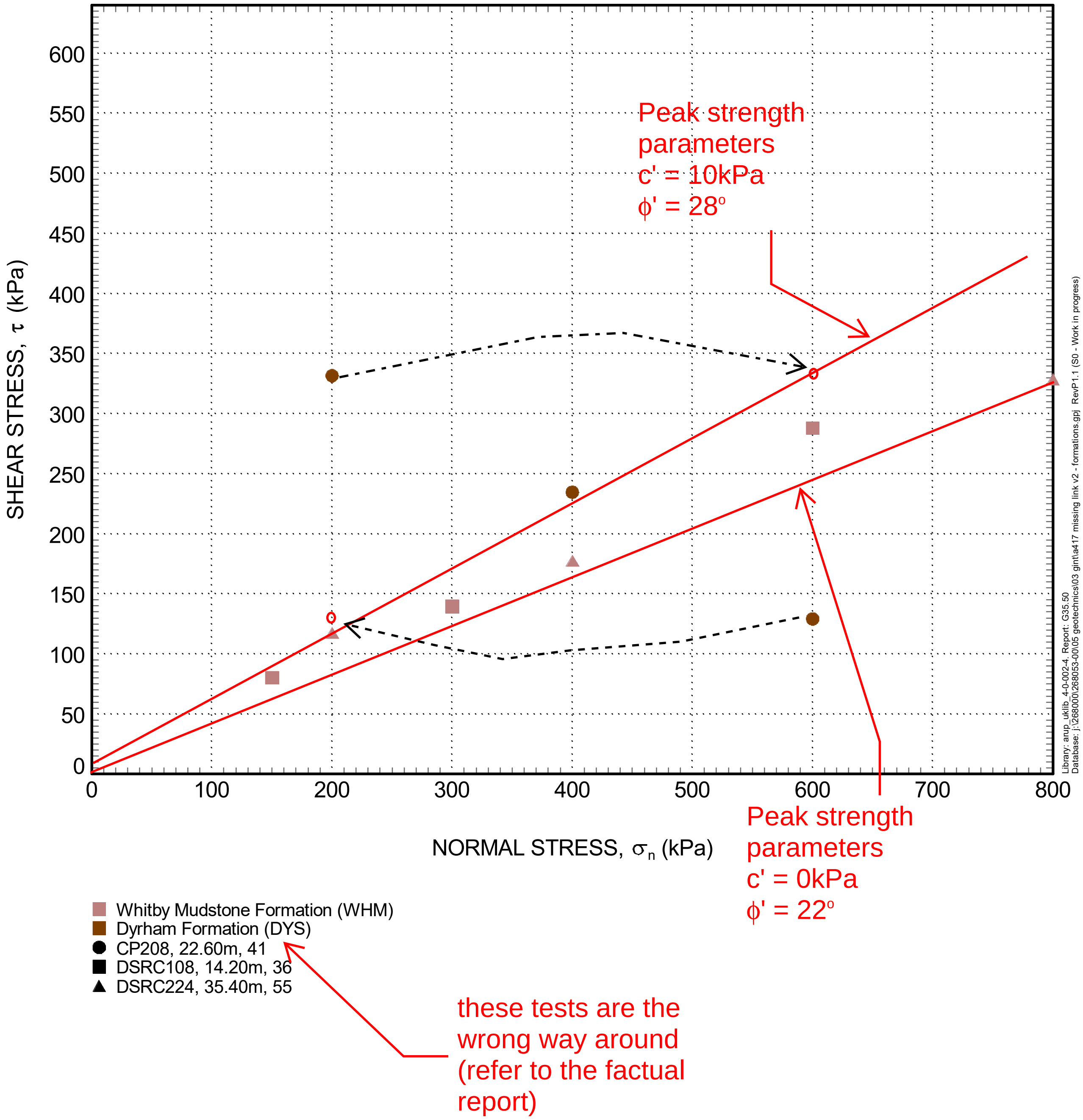
Whitby Mudstone Formation (WHM)
Dyrham Formation (DYS)
Charmouth Mudstone Formation (CHAM)
CP202
CP204
CP210
CP211
CP213
CP214
CP215
CP217
DSRC107
DSRC109
DSRC205
DSRC229
DSRC301
DSRC319
DSRCOH304

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNDRAINED SHEAR STRENGTH FROM SPT

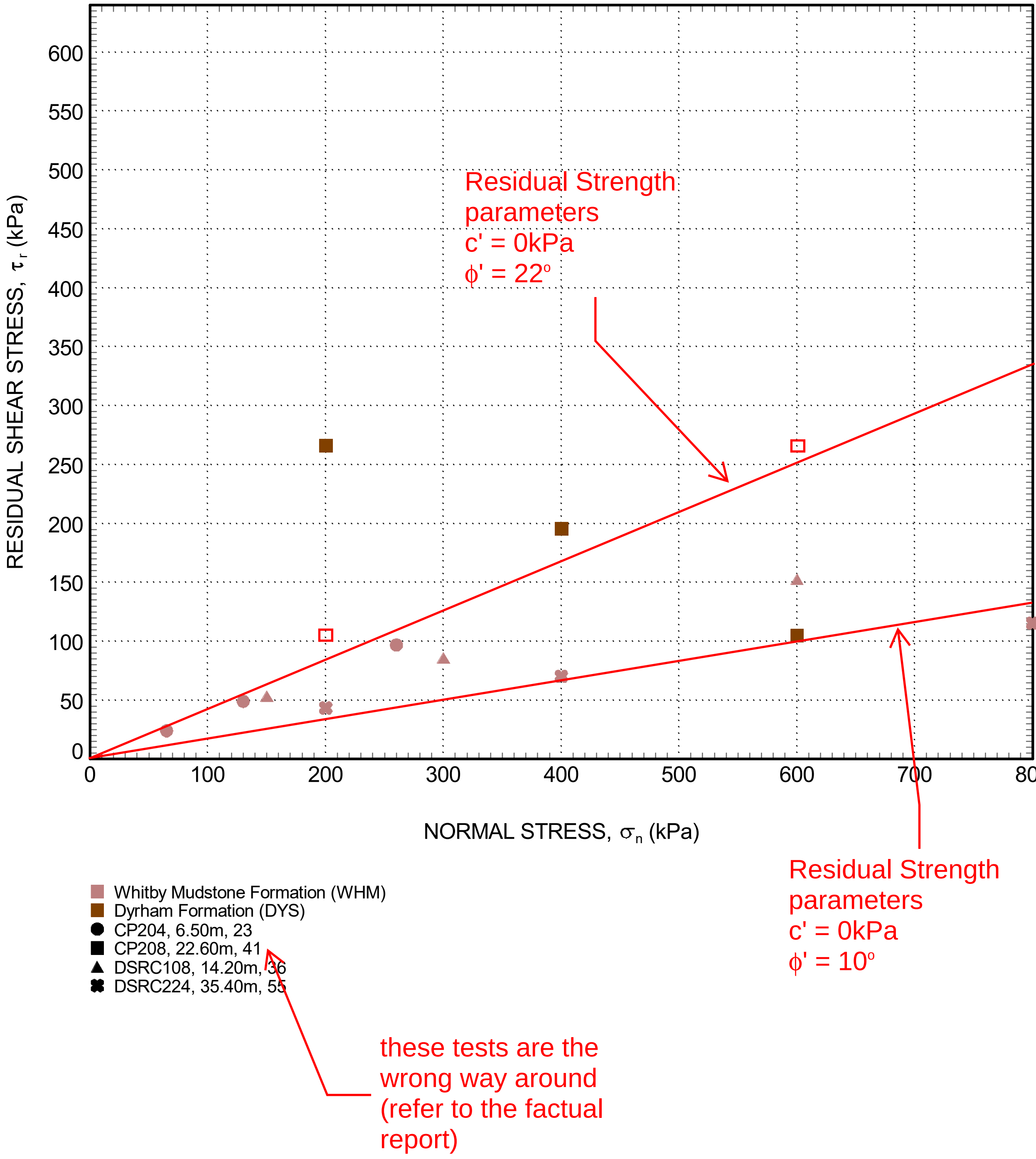
LIAS GROUP

FIGURE: F10.10



A417 - MISSING LINK
SHEAR BOX TESTS
LIAS GROUP

FIGURE: F10.11



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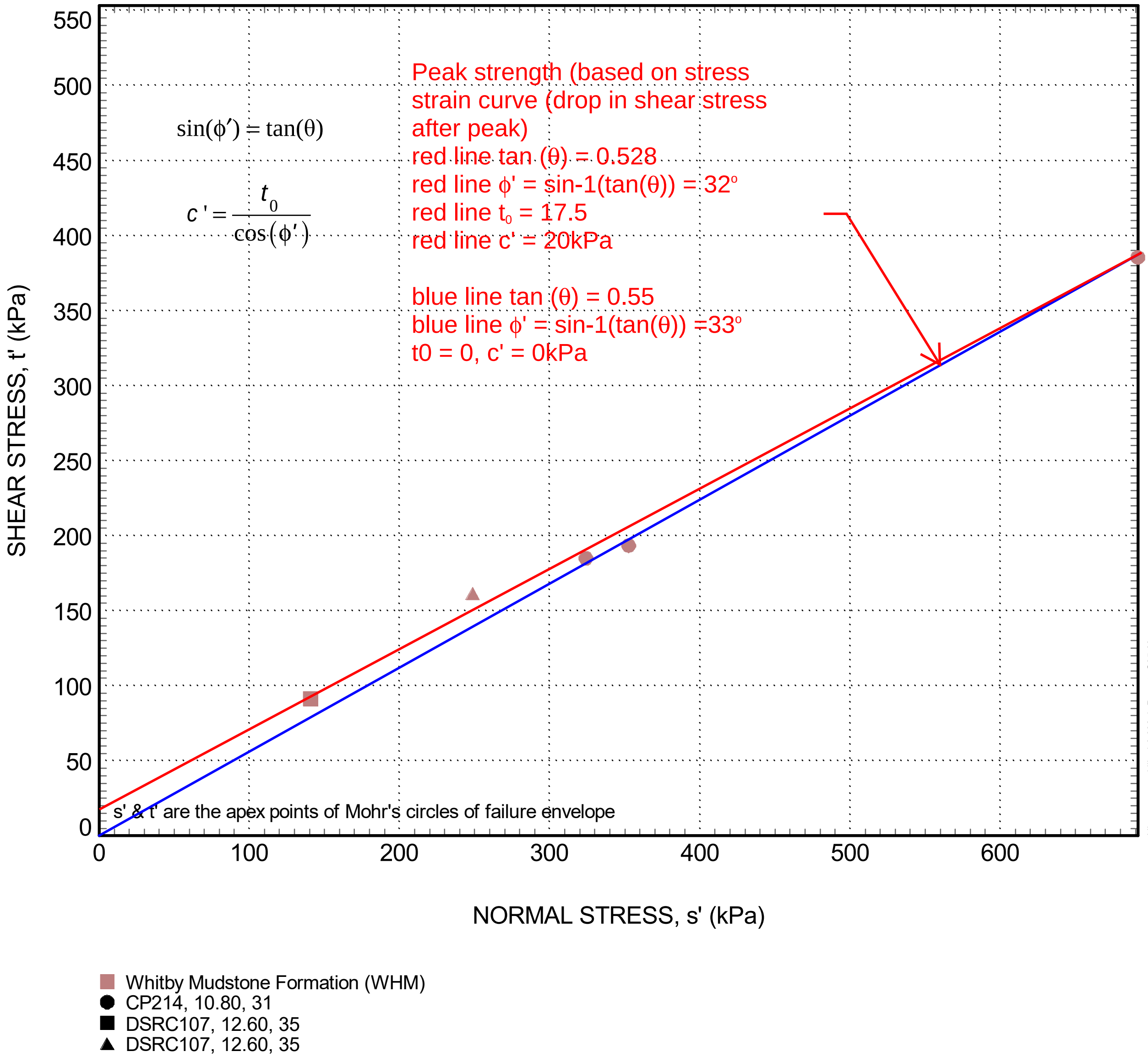
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

A417 - MISSING LINK
SHEAR BOX TESTS
LIAS GROUP

FIGURE: F10.12

ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21



Library: arup_uklib_4-0-002-4. Report: G35.60
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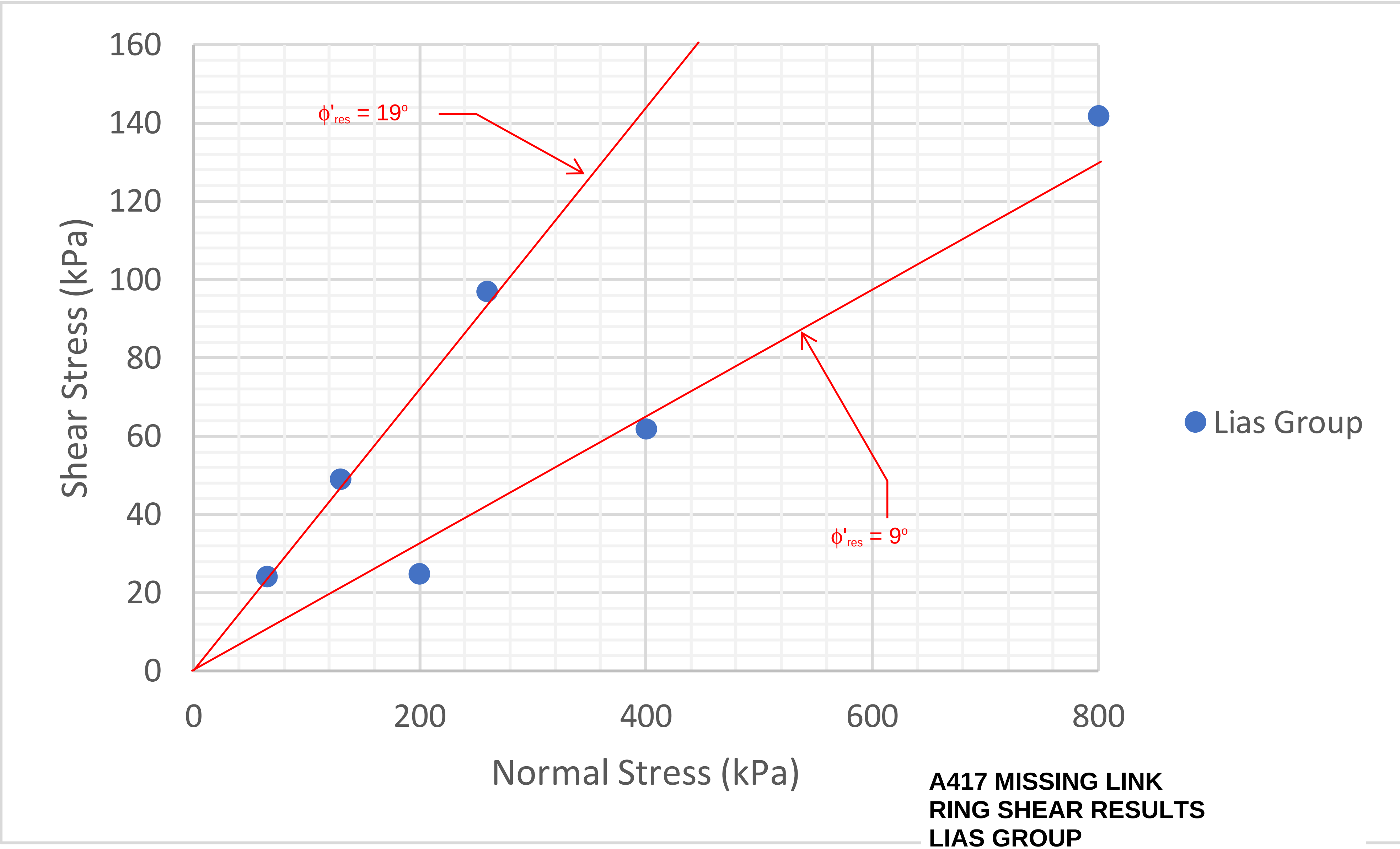
ARUP. gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
TRIAXIAL T' V S'

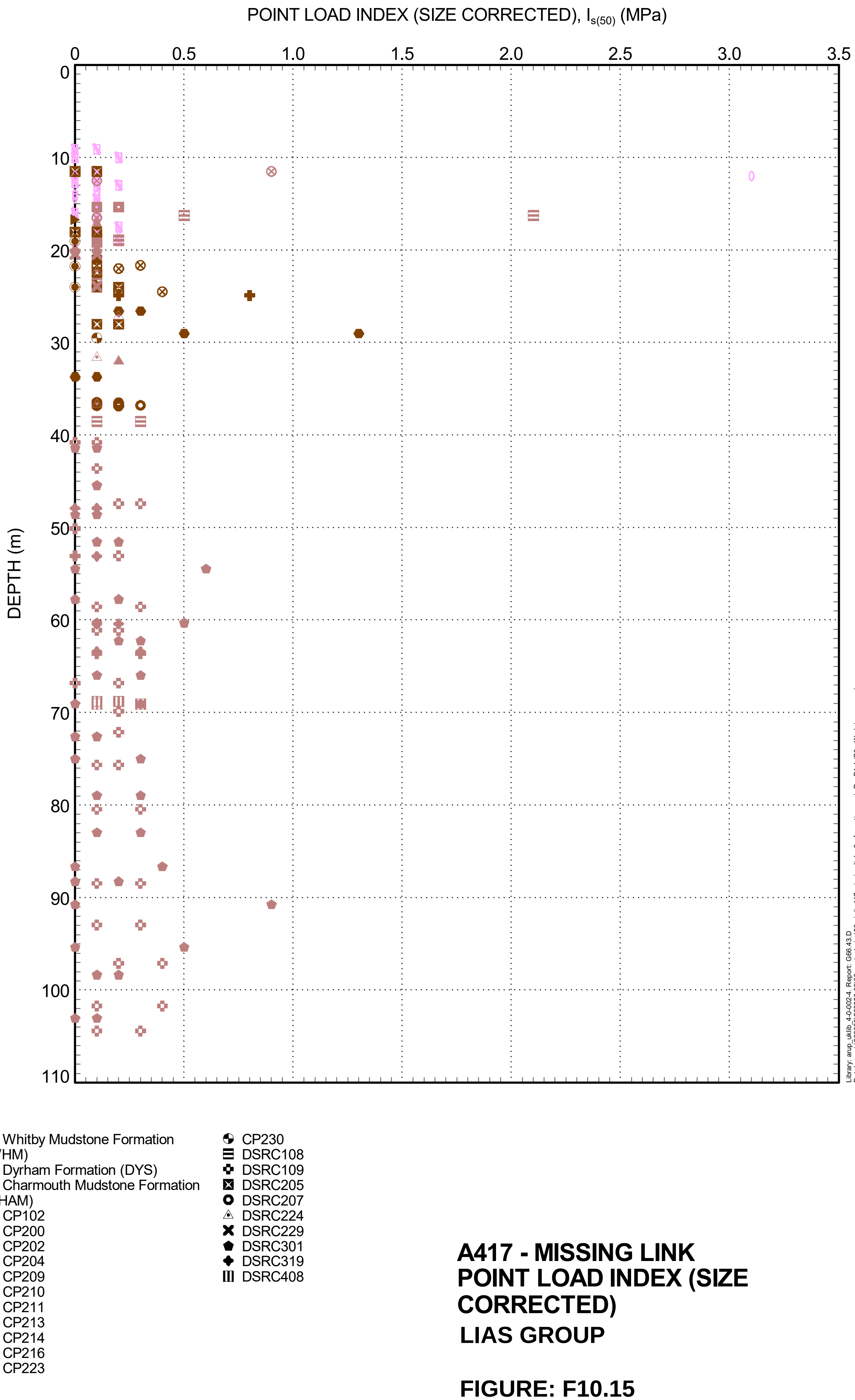
LIAS GROUP

FIGURE: F10.13



A417 MISSING LINK
RING SHEAR RESULTS
LIAS GROUP

FIGURE: F10.14

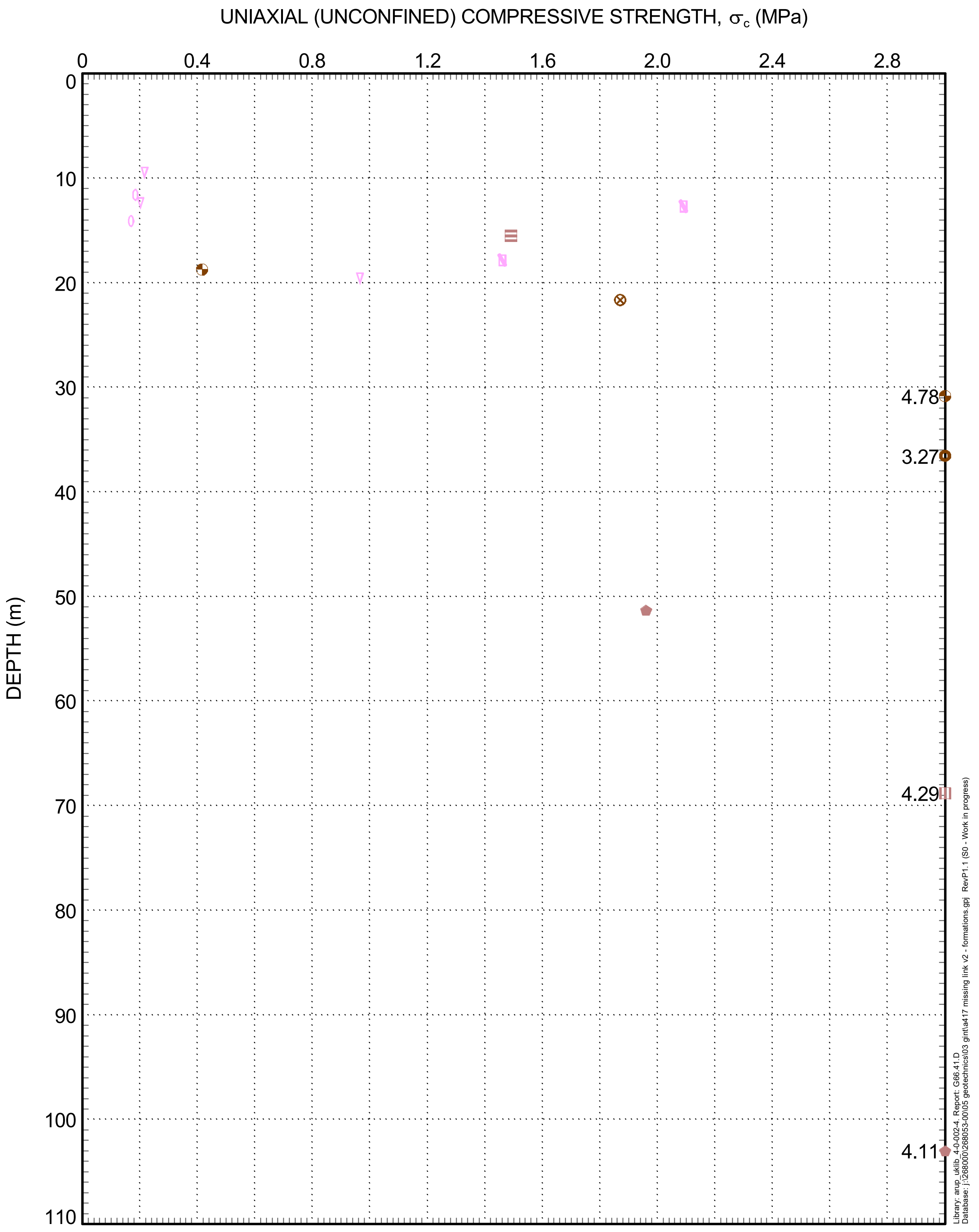


Library: arup_uklib_4-0-002-4, Report: G66.43.D
Database: j:\268000\268053-00\05 geotechnics\03 gint\a417 missing link v2 - formations.gpj RevP1.1 (S0 - Work in progress)

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
POINT LOAD INDEX (SIZE CORRECTED)
LIAS GROUP

FIGURE: F10.15

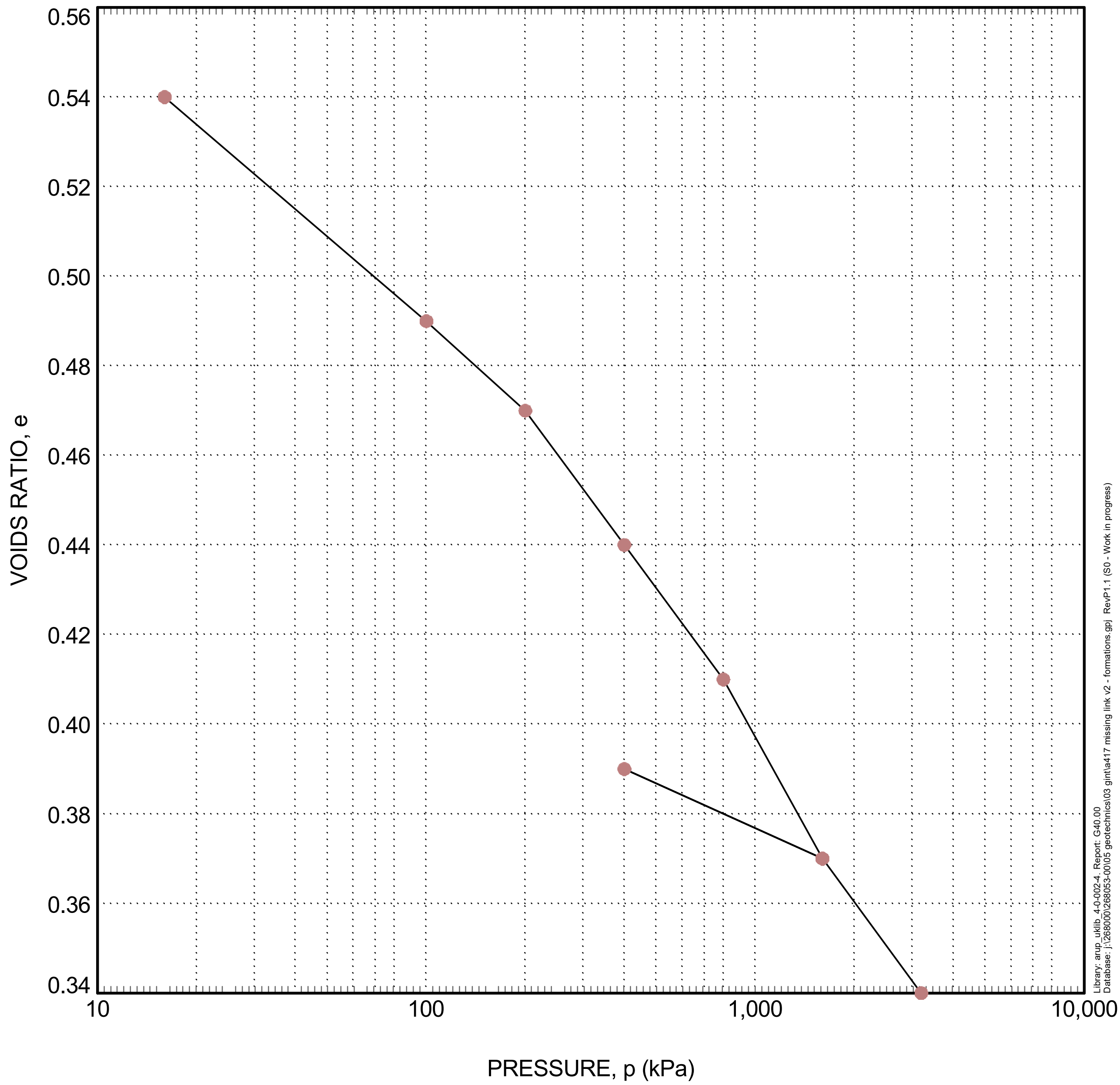


Whitby Mudstone Formation (WHM)
Dyrham Formation (DYS)
Charmouth Mudstone Formation (CHAM)
CP102
CP200
CP202
CP204
CP230
DSRC108
DSRC207
DSRC301
DSRC408

ARUP_gINT v10.00.01.07
Made by Edward Boss on 4-Mar-21

A417 - MISSING LINK
UNIAXIAL COMPRESSIVE STRENGTH
LIAS GROUP

FIGURE: F10.16



Whitby Mudstone Formation (WHM)
DSRC301, 41.31, 47

A417 - MISSING LINK
CONSOLIDATION TESTS
LIAS GROUP

FIGURE: F10.17

Appendix G BRE testing summary table

Table G-1 Summary table BRE Testing

Hole	Sample Depth (m)	Sample ref.		Strata	WS (mg/l)	pH	AS (%)	TS (%)	TPS (%)	OS (%)	OS > 0.3%
DSRC107	1.2	L	8	MMD (Crickley Hill)	<10	8.6	0.03	0.03	0.09	0.06	N
TP205	2.4	D	8	MMD (Crickley Hill)	<10	8.2	0.09	0.06	0.18	0.09	N
TP207	3.9	BLK	12	MMD (Crickley Hill)	560	7.8	0.19	3.90	11.70	11.51	Y
CP106	4.8	D	17	MMD (Crickley Hill)	1400	6.3	0.57	1.40	4.20	3.63	Y
DSRC207	5.2	C	17	MMD (Crickley Hill)	<10	9.2	0.03	0.02	0.06	0.03	N
CP105	5.8	D	23	MMD (Crickley Hill)	<10	8.2	0.01	0.02	0.06	0.05	N
CP216	6.2	D	16	MMD (Crickley Hill)	20	8.2	0.09	0.06	0.18	0.09	N
CP213	10	L	30	MMD (Crickley Hill)	510	7.9	0.12	0.90	2.70	2.58	Y
CP106	10.5	D	35	MMD (Crickley Hill)	1400	7.7	0.43	0.79	2.37	1.94	Y
DSRC229	10.7	D	36	MMD (Crickley Hill)	270	8.1	0.07	0.38	1.14	1.07	Y
DSRC207	12	CS	25	MMD (Crickley Hill)	140	8.6	0.05	0.38	1.14	1.09	Y
CP210	16.5	C	29	MMD (Crickley Hill)	610	6.8	0.14	0.61	1.83	1.69	Y
TP606	0.5	B	5	Head	<10	8.7	0.02	0.03	0.09	0.07	N
RC516	1	D	6	Head	<10	8.5	0.03	0.03	0.09	0.06	N
OH411	3.2	C	12	GOG – Limestone	<10	8.4	0.12	0.08	0.24	0.12	N
DSRC312	4.53	CS	14	GOG – Limestone	<10	8.8	0.01	0.02	0.06	0.05	N
OH411	6.2	C	16	GOG – Limestone	<10	8.4	0.01	0.04	0.12	0.11	N
DSRC312	9.85	CS	21	GOG – Limestone	<10	8.9	0.03	0.03	0.09	0.06	N
DSRCOH400	1.85	CS	7	GOG – Fuller's Earth	<10	8.2	0.07	0.09	0.27	0.20	N
DSRC329	2.8	CS	9	GOG – Fuller's Earth	280	7.8	0.22	1.20	3.60	3.38	Y
DSRC220	5.4	CS	11	GOG – Fuller's Earth	700	7.8	0.41	1.40	4.20	3.79	Y
DSRCOH412	9.15	CS	27	GOG – Fuller's Earth	670	7.7	0.35	1.10	3.30	2.95	Y
DSRC220	14.3	CS	23	GOG – Fuller's Earth	190	8.2	0.21	1.10	3.30	3.09	Y
DSRC327	17.44	CS	28	GOG – Fuller's Earth	200	8.4	0.17	1.30	3.90	3.73	Y
DSRC218	18.9	CS	27	GOG – Fuller's Earth	180	8.4	0.13	0.91	2.73	2.60	Y

Hole	Sample Depth (m)	Sample ref.		Strata	WS (mg/l)	pH	AS (%)	TS (%)	TPS (%)	OS (%)	OS > 0.3%
DSRC326	20.85	CS	26	GOG – Fuller's Earth	190	8.4	0.11	0.78	2.34	2.23	Y
DSRC310	3.46	CS	12	IOG	<10	8.3	0.06	0.04	0.12	0.06	N
RC516	4.2	C	11	IOG	<10	8.7	0.03	0.04	0.12	0.09	N
DSRC311	5.2	CS	16	IOG	30	8.1	0.06	0.22	0.66	0.60	Y
DSRC319	6.9	D	15	IOG	<10	8.1	0.02	0.04	0.12	0.10	N
DSRC310	7.47	CS	15	IOG	70	8.1	0.06	0.06	0.18	0.12	N
DSRC311	10.73	CS	22	IOG	<10	8.3	0.06	0.06	0.18	0.12	N
RC516	11.15	CS	20	IOG	<10	8.8	0.04	0.05	0.15	0.11	N
DSRC319	12.75	CS	23	IOG	<10	8.7	0.06	0.03	0.09	0.03	N
DSRCOH400	14.48	CS	28	IOG	400	7.7	0.21	1.30	3.90	3.69	Y
DSRC319	19.1	CS	29	IOG	500	7.9	0.09	0.58	1.74	1.65	Y
DSRC319	24.3	D	35	LG – Bridport Sand	840	7.6	0.15	1.40	4.20	4.05	Y
DSRC325	25.9	D	45	LG – Bridport Sand	440	7.0	0.12	1.30	3.90	3.78	Y
DSRCOH304	30.6	CS	54	LG – Bridport Sand	240	7.9	0.06	1.10	3.30	3.24	Y
DSRC319	33.3	D	46	LG – Bridport Sand	510	7.9	0.11	1.20	3.60	3.49	Y
DSRC107	11	D	33	Lias Group	390	8.1	0.12	0.29	0.87	0.75	Y
CP215	11.5	C	41	Lias Group	300	7.8	0.16	0.56	1.68	1.52	Y
DSRC205	13	C	36	Lias Group	770	7.6	0.15	0.76	2.28	2.13	Y
DSRC109	40.1	C	46	Lias Group	540	8.2	0.11	1.30	3.90	3.79	Y
DSRC301	43.6	CS	50	Lias Group	410	8.2	0.08	0.66	1.98	1.90	Y
DSRC319	45.4	D	63	Lias Group	200	8.3	0.04	0.39	1.17	1.13	Y
DSRC319	51.45	D	70	Lias Group	410	8.2	0.08	0.61	1.83	1.75	Y
DSRC319	58.9	C	78	Lias Group	770	8.5	0.24	2.00	6.00	5.76	Y

Appendix H Land contamination risk assessments

H.1 Introduction

H.1.1.1 The scheme is located within a complex and sensitive environmental setting with the water environment comprising number of surface water watercourses across three different catchments and interlinked with groundwater resources. The water environment supports reach biodiversity and landscape features.

H.1.1.2 Construction of the proposed A417 scheme will require significant earthworks and materials movement across the whole of the alignment. Due to the sensitive setting of the scheme with respect to the water environment, management of materials potentially impacted by historical and/or current activities will require particular consideration.

H.1.1.3 This appendix sets out a conceptual site model and presents preliminary and generic quantitative risk assessments with respect to land contamination that provide basis to geo-environmental considerations set out in the main report and also to environmental impact assessments set out in the Environmental Statement - Document Reference 6.2.

H.2 Ground investigations and surveys

H.2.1.1 There has been a number of historical ground investigations (GI) along and within the vicinity of the current A417 alignment and the proposed scheme. Details are provided within ES Appendix 9.1 Preliminary sources study report (Document Reference 6.4). These investigations primarily focused on geotechnical design aspects, however information obtained from these works, i.e. the location and description of the encountered made ground, has been reviewed as part of the baseline land contamination assessments.

H.2.1.2 The proposed scheme has been investigated through scheme specific ground investigations as detailed in the main report. The geo-environmental scope of the GI has been informed by the locations of potential sources of contamination identified in the ES Appendix 9.1 Preliminary sources study report (Document Reference 6.4). Based on the strategy derived for the intrusive investigations, contamination laboratory testing has been undertaken on any encountered made ground materials and/or materials exhibiting visual or olfactory evidence of contamination. The suite of testing, as presented in the initial GI specification and modified in the addendum, are aimed at general characterisation of made ground or contamination to allow for assessment of chemical suitability for reuse and assessment of risks to human health and controlled waters during construction and operation. No testing of natural ground was undertaken.

H.2.1.3 Groundwater sampling was completed over one round of sampling during the Phase 1 investigations in two borehole installations (February 2019) and three rounds during the Phase 2A investigations following the completion of individual installations rather than on completion of all field works. This is due to the programme constraints and land access issues. Details of hydrogeological investigations are presented in Section 5.17 of the main report. In summary, the groundwater monitoring aimed at obtaining baseline information to characterise main hydrogeological units within the scheme area with respect to groundwater regime and quality. The groundwater level monitoring is still on-going and any additional results will be considered at detailed design.

H.2.1.4 Surface water quality monitoring has been undertaken in the area of the Norman's Brook tributary (two sampling locations) within the scheme footprint, as well as further away from the scheme - the Frome and the Churn and selected tributaries (four sampling locations). The aim of the surface water quality monitoring was to obtain baseline information on watercourses within the study area derived for the environmental impact assessments. Refer to the Environmental Statement - Document Reference 6.2 for details. Six rounds of monthly sampling and testing has been completed up to end of December 2020. The surface water sampling and testing is currently on-going and any additional results will be considered at detailed design.

H.2.1.5 The geo-environmental assessments are based on the chemical data obtained from Phase 1 and Phase 2A ground investigations and surface water surveys:

- Phase 1 investigations testing: 3No. soil samples, 3No. soil leachate analyses and 2No. groundwater samples.
- Phase 2A investigations testing: 20No. soil samples, 16No. soil leachate analyses, 78No. groundwater samples and 12No surface water samples (scheme area).

H.2.1.6 The results are summarised in Annex A.

H.2.2 Encountered ground and groundwater conditions

H.2.2.1 Encountered ground and groundwater conditions are presented in the main report. In summary the majority of the scheme alignment was found to be underlain by natural ground with limited areas of made ground. The nature of the encountered made ground is reviewed in more detail below.

H.2.2.2 Groundwater conditions vary significantly across the scheme and are dependent on hydrogeological setting. The main hydrogeological units relevant to these assessments are mass movement deposits in the Crickley Hill escarpment and Inferior Oolite Group limestones draining via springs into the tributary to Norman's Brook, and Great Oolite Group limestones also draining via springs to the River Churn tributaries and the River Frome. Groundwater level monitoring data is summarised in the main report. Detailed hydrogeological model is presented in ES Appendix 13.7 Hydrogeological impact assessment (Document Reference 6.4) and also summarised in the main report.

H.2.3 Made ground and evidence of contamination

H.2.3.1 A review of the exploratory hole logs from historical and recently completed GIs indicated made ground to be heterogeneous. It primarily comprises natural reworked materials of sands, gravels, silts and clays. Topsoil was also often logged as made ground, which is not considered to be a potential source of contamination. In some areas such as fields located on either side of the existing A417 climbing escarpment section and infilled land at Grove Farm/Crickley Hill Tractors, made ground was recorded to contain anthropogenic inclusions mainly brick and concrete, which are a potential source of asbestos. Slag, clicker and ash, and also olfactory evidence of hydrocarbon contamination (CP106) were primarily recorded in the area Grove Farm/Crickley Hill Tractors. These are considered to be a source of metals and polycyclic aromatic hydrocarbons (PAHs), and potentially asbestos. Tarmacadam or bituminous surfacing and also tarmacadam inclusions were recorded in areas of car parking or road network, which may be a source of PAHs (dependent on age). Summary of encountered evidence of potential contamination is presented in Table H-1.

Table H-1 Encountered made ground exhibiting visual/olfactory evidence of contamination

Exploratory Hole ID	Investigation location	Identified evidence of potential contamination
1990a_B322	Crickley Hill escarpment (southern and northern) lower section	Brick fragments (0.2-0.5m bgl)
1990b_B64		Brick inclusions (0.5-1.1m bgl)
CP200		Tarmacadam (0-0.1 m bgl) Brick, tile, clinker concrete, wood and plastic sheet inclusions (0.1-0.9m bgl) Concrete (0.9-0.95m bgl)
2009a_BH01	Crickley Hill escarpment (southern and northern) middle section	Concrete and brick inclusions (0-0.2m bgl) Possible concrete footing (5-5.5m bgl)
2009a_BH04		Brick and glass inclusions (0 – 0.2m bgl)
2009b_TP601		Brick and concrete inclusions (0.6-4.1m bgl0
CP105		Charcoal inclusions (1.2-2.75m bgl)
TP207		Fragments of charcoal inclusions (0-0.25m bgl)
CP213		Ceramic inclusions (0-0.9m bgl)
CP215		Brick and glass inclusions (0.3-0.4m bgl) Brick, concrete and slate (0.4-0.7m bgl)
2002_W02	Grove Farm/ Crickley Hill Tractors	Ash and brick fragments inclusions (0.3 – 3m bgl)
2002_W03		Ash and clicker inclusions (1.8-2m bgl) Brick fragments inclusions (3.5-5m bgl)
CP106		Ashy slag, clinker and concrete inclusions (0-0.4m bgl) Slag, concrete, brick and hydrocarbon odour (0.4 – 0.75m bgl) Slag inclusions (0.75-1.3m bgl and 1.9-2.6m bgl)
DS/RC107		Brick inclusions (0.1-0.55m bgl) Concrete, brick and bituminous material inclusions (0.55-1.2m bgl)
DS/RC108		Ceramic, tarmacadam, terracotta and glass inclusions (0.2 – 1.45m bgl)
DS/RC418	Crickley Hill visitors centre car park	Tarmacadam (0-0.2 m bgl)
OH405	Air Balloon PH car park	Brick inclusions (0.15-0.9m bgl)
DS/RC110		Tarmacadam (0-0.1 m bgl)
RC509		Clicker inclusions (0-0.1m bgl) Clicker and brick (0.1-0.4m bgl)
1983_BH17	Existing A417 (top of escarpment)	Brick fill (0-0.3m bgl)
1983_BH1B		Bituminous surfacing (0-0.1m bgl)
DS/RC419	Barrow wake car park	Tarmacadam (0-0.15 m bgl)
DS/RC404		Tarmacadam (0-0.17 m bgl and 0.3-0.4m bgl) Tarmacadam inclusions (0.4-0.45m bgl)

Exploratory Hole ID	Investigation location	Identified evidence of potential contamination
OH416	Farm access (towards Birdlip)	Tarmacadam (0-0.15 m bgl)
DS/RC415		Tarmacadam (0.3-0.6 m bgl)
99-SO91NW156	Existing A417 (Nettleton)	Brick inclusions (0 -0.3m bgl)
99-SO91SW47		Brick and glass inclusions (0 – 0.2m bgl)

H.3 Risk assessment methodology

H.3.1.1 Assessment of risks in relation to contamination were undertaken in accordance with industry best practice presented in Land Contamination Risk Management guidance (www.gov.uk replacing CLR11[1]). The risk assessment process is underpinned throughout by the development of the Conceptual Site Model (CSM), which provides a schematic representation of identified contaminant linkages.

H.3.1.2 The process comprises a tiered approach, which starts with a Tier 1: Preliminary Risk Assessment (PRA). Any potential risks identified at Tier 1 would be studied in more detail through a Tier 2: Generic Quantitative Risk Assessment (GQRA). The results of any investigations completed is reviewed at this stage and quantitative assessment is undertaken. The methodology for a GQRA is presented below for human health and controlled waters.

H.3.1.3 If a Tier 2 assessment identifies potential risk, i.e. the applied generic assessment criteria are exceeded, a Tier 3: Detailed Quantitative Risk Assessment (DQRA) is required. This involves derivation of site-specific assessment criteria and may involve additional targeted ground investigations to refine the CSM. Where pollutant linkages are identified as viable on completion of Tier 3 assessments, remediation mitigation measures would be identified. However, the detailed design of how required mitigation would be implemented would be completed at a detailed design stage, including remedial options appraisal and remediation and verification plan.

Tier 1: PRA methodology

H.3.1.4 The plausible pollutant linkages within the conceptual site model have been evaluated in accordance with CIRIA 552[2]. The Tier 1: PRA comprise a simple and conservative assessment of potential risks from possible pollutant linkages (Source-Pathway-Receptor). At this stage potential pollutant linkages are identified. Where suitable investigation data exists to assess these, the data is used to ascertain whether a risk exists. If suitable investigation data does not exist, the required investigations to confirm whether such a linkage is viable is defined, e.g. where there is a possibility of presence of made ground, soil sampling and laboratory testing would be identified as the required investigation.

[1] Model Procedures for the Management of Land Contamination, CLR11, 2004, Environment Agency; to be withdrawn by end of 2019 and replaced by governmental advice on Land contamination: risk management https://www.gov.uk/guidance/land-contamination-how-to-manage-the-risks
[2] CIRIA (2001), Contaminated land risk assessment- A guide to good practice (C552)

Tier 2: GQRA methodology – human health

H.3.1.5 Where a potential pollution linkage is identified in relation to human health a Tier 2: GQRA is undertaken on available data. To simplify the assessment process, the guidance suggests that generic soil quality guideline values have been used for initial screening of soil contamination testing results. This is on conditions that such guidelines are available and are appropriate to the site circumstances and the relevant pollutant linkages. This is done by screening available soil chemical test results against published generic assessment criteria for a suitable land use scenario.

H.3.1.6 Where available, the results have been screened against the DEFRA 'Category 4 Screening Levels' (C4SLs)[3], which evaluate whether the assessed land is suitable for use. In the absence of 'C4SLs', the Land Quality Management 'Suitable for Use Levels' (S4ULs)[4] have been used, which are based on health criteria that represent minimal or tolerable levels of risk to health. In the absence of C4SLs and S4ULs for certain determinands (i.e. cyanide), Arup Generic Assessment Criteria (GACs) have been used.

H.3.1.7 The applied assessment criteria, as per paragraph above, have been derived using the Environment Agency Contaminated Land Exposure Assessment (CLEA) model. This model defines age classes for receptors within a number of generic end use scenarios.

Tier 2: GQRA methodology – controlled waters

H.3.1.8 The assessment of risk to controlled waters has been undertaken in accordance with the current Environment Agency's published guidance [5][6] and the Remedial Targets Methodology[7]. Where a potential pollution linkage is identified in relation to controlled waters a Tier 2: GQRA is undertaken on data obtained from soil leachate, groundwater and surface water laboratory testing. Where impact on surface waters is being assessed, this is achieved by screening available water chemical testing results against the Environmental Quality Standards for annual average inland surface water (freshwater) values (FEQS) [8]. Assessing the impact on drinking water resources is achieved by screening available water chemical testing results against UK Drinking Water Standards (UK DWS)[9]. Measured concentrations of petroleum hydrocarbons have been screened against assessment criteria set out in CL: AIRE guidance on petroleum hydrocarbons in groundwater (CL:AIRE TPH AC)[10].

H.3.1.9 Where the Freshwater Environmental Quality Standards (FEQS) are dependent on bioavailability, which is the case for copper, lead, manganese, nickel and zinc, the bioavailable fractions have been derived using the UKTAG Metal

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[3] Defra, Development of Category 4 Screening levels for assessment of land affected by contamination, SP1010, Final Project report (Revision 2), September 2014.
[4] Paul Nathaniel et al., The LQM /CIEH S4ULs for Human Health Risk Assessment, Version 1.0, February 2015.
[5] Department for Environment and Rural Affairs, "Groundwater Protection," 14 March 2017. [Online]. Available: https://www.gov.uk/government/collections/groundwater-protection.
[6] Environment Agency, "The Environment Agency's approach to groundwater protection," February 2018. [Online]. Available: https://www.gov.uk/government/publications/groundwater-protection-position-statements.
[7] Remedial Targets Methodology, Hydrogeological Risk Assessment for Land Contamination, Environment Agency 2006
[8] The Water Framework Directive (Standards & Classification) Directions (England and Wales), Department for Environment Food and Rural Affairs (Defra), 2015
[9] United Kingdom Drinking Water Standards, UK Drinking Water Inspectorate, 2017
[10] Petroleum Hydrocarbons in Groundwater: Guidance on assessing petroleum hydrocarbons using existing hydrogeological risk assessment methodologies, CL:AIRE 2017

Bioavailability Assessment Tool (M-BAT) [11]. The bioavailable fractions concentrations depend on receptor waters proprieties including its pH and calcium and dissolved organic carbon (DOC) concentrations. These have been obtained from surface water quality monitoring. In accordance with UKTAG M-BAT, the following values have been applied within the model:

- Calcium – 105mg/l. This represents an average of calcium concentrations obtained from surface water monitoring.
- DOC – 2.45mg/l. DOC was not tested in surface water and instead Total Organic Carbon (TOC) used. Median concentration of TOC recorded over surface water monitoring intervals, which was similar to the median concentration of DOC in groundwater, 2.5mg/l.
- pH – 8.1 pH Units. This represents an average of pH values recorded in surface water monitoring.

H.4 Conceptual Site Model

Introduction

H.4.1.1 The nature of potential Source-Pathway-Receptor linkages identified in the CSM have been separated into those related to the baseline and operational conditions, as well as pollutant linkages introduced during construction. As part of the scheme includes the existing A417, the operational conditions will be similar to those at baseline.

H.4.1.2 Upon the identification of plausible pollutant linkages from the proposed Source-Pathway-Receptor based on the conceptual site model, suitable investigation data have been used to assess whether a risk exists to the identified receptors. This informed the Tier 1 human health and controlled waters risk assessments.

H.4.1.3 The baseline conditions of the CSM have been informed by available investigations and extensive desk-based information for the site. In relation to the potential impacts of construction, the CSM has been developed with consideration of the construction processes that are anticipated to be required – i.e. to allow construction the proposed scheme. This includes the following proposed works:

- construction of earthworks (including earth embankments and excavations)
- piling
- installation of drainage (highway and ground stabilisation) and culverts
- de-trunking works along the existing alignment.

H.4.1.4 The assessment of the potential impacts on controlled waters from scheme construction including fuel spillages or leakages, cementitious grout contamination of groundwater and surface water from piling, soil nailing and rock anchors, etc are considered in ES Chapter 13 Road drainage and water environment (Document Reference 6.2).

Sources

H.4.1.5 The potential sources of contamination have been distinguished into on-site and off-site sources as detailed in Table H-2 and Table H-3. For the purpose of the

[11] Metal Bioavailability Assessment Tool (M-BAT), Water Framework Directive UKTAG (WFD UKTAG), version 30 Environment Agency 2013

CSM, those sources listed as on-site relate to locations within the redline boundary. Sources identified outside this area but within the boundaries of the study area (500m buffer around the DCO area) are deemed to be off-site sources. These are presented in ES Chapter 9 Geology and soils (Document Reference 6.2).

Table H-2 Potential sources of contamination (on-site)

Potential source	Potential contaminants
Made ground soils	
Possible made ground associated with existing road infrastructure (A417 and other routes crossing the proposed scheme): • 0+000 to 2+120 (A417) • 2+850 (access road) • 4+020 (Stockwell Lane) • 4+700 (Cowley Bridleway) • 5+200 to 5+760 (A417)	Metals, hydrocarbons, asbestos, herbicides in soils and groundwater, ground gas
Areas of known made ground identified during ground investigations completed to date, including Grove Farm/Crickley Tractors area. Locations shown in ES Chapter 9 Geology and soils (Document Reference 6.2).	
Filled ground other than that of the A417 embankment	Metals, hydrocarbons, asbestos, herbicides, ground gas
Made ground associated with private development/farmland crossing the proposed scheme.	
Historical infilled quarries	
Birdlip Quarry, now partially infilled and used as a motocross track, partially overlaps with the scheme footprint at approximate chainage 4+860 to 5+100. Backfill materials are unknown. There is a risk of un-recorded features being encountered along the proposed scheme.	Heavy metals, hydrocarbons, asbestos, ground gas
Current or historical activities	
Activities associated with the operation of the existing road infrastructure (A417 and other routes crossing the proposed scheme). These activities may have resulted in accidental spillages/leakages of fuels/oils, gradual discharge of fuel/oil contaminated runoff into defective drainage networks and release to the surrounding ground. It may also include fly tipped materials on minor roads and tracks. Not all areas have been identified. These localised areas of contamination may be encountered during construction.	Metals, hydrocarbons, asbestos
Highways drainage discharges into the ground through soakaways and consented and non-consented sewage discharge. They also have potential to be conduits for contamination release to the local groundwater.	Metals, hydrocarbons, pathogens
Current or historical land uses: • Radio masts with associated electricity substation • Agricultural machinery operation – Grove Farm/Crickley Hill Tractors The main historical and current land use in the study area is for agricultural purposes. There is potential for the accumulation of herbicides and pesticides in the site soils along the proposed scheme.	Metals, hydrocarbons, asbestos, PCBs, herbicides and pesticides, ground gas
Environment Agency Recorded pollution incidents:	Leachate, metals

• Inert Materials and Wastes – Category 3 Minor	
Contaminated groundwater	
Impact of the above listed sources on groundwater in the vicinity of sources	Metals, hydrocarbons, herbicides, PCBs
Impact of the above listed source on groundwater through leakages/spills (e.g. vehicle servicing)	Hydrocarbons

Table H-3 Potential sources of contamination (off-site)

Potential Source	Potential Contaminants
Potential made ground soils	
Made ground associated with existing road infrastructure (A417 and other routes in close proximity to the proposed scheme) that may have impacted, or be impacting, on the proposed scheme via dust migration, leaching and migration of contamination or migration of ground gas. There are numerous areas where this is possible over much of the route. Individual locations are not listed for brevity. Not all areas have been identified.	Metals, hydrocarbons, herbicides in soils, ground gas
Made ground associated with private development/farmland in close proximity to the proposed scheme. There is a potential risk in all areas of the route. Not all areas have been identified.	Metals, hydrocarbons, asbestos, herbicides in soils, ground gas
Historical infilled quarries	
Historical backfilled quarries in close proximity to the proposed scheme including Birdlip Quarry, overlapping with the scheme and extending outside the scheme footprint. Other identified infilled quarries are located at least 210m away from the scheme. There is a risk of unrecorded features being encountered in the study area.	Metals, hydrocarbons, asbestos, ground gas
Historical landfill	
Crickley Lodge Historical Landfill (six individual cells) used for inert disposal adjacent to the northern footprint of the proposed scheme near Crickley Hill. Southernmost cell is adjacent to the scheme boundary at approximate Ch0+900. The reminder of cells are located approximately between 70 and 220m to the north.	Metals, hydrocarbons, asbestos, leachate, ground gas
Current or historical activities	
Activities associated with the operation of existing road infrastructure (A417 and other routes in close proximity to the proposed scheme). These activities may have resulted in accidental spillages/leakages of fuels/oils, gradual discharge of fuel/oil contaminated runoff into defective drainage networks and release to the surrounding ground. May also include fly tipped materials on more minor roads and tracks.	Metals, hydrocarbons, asbestos
Current or historical land uses (excluding landfill/quarries): • Coach hire services • Sewage Works The main historical and current land use in the location of the proposed scheme is for agricultural purposes. There is potential for the accumulation of herbicides and pesticides in soils in areas close to the proposed scheme.	Metals, hydrocarbons, asbestos, herbicides, PCBs (electricity substations)
Nine consented soakaway discharges, the located approximately between 30m and 390m away from the scheme. Whilst some are for infiltration of surface water (rain) some are sewage discharges. They also have the potential to be conduits for contamination release to the local groundwater.	Metals, hydrocarbons

Contaminated groundwater	
Impact of the above listed sources on groundwater near sources.	Metals, hydrocarbons, herbicides, PCBs
Impact of the above listed source on groundwater through leakages/spills.	Hydrocarbons

H.4.1.6 There are no historical landfills within the DCO boundary of the scheme. However, a historical landfill is located on the northern slope of Crickley. This comprises six small cells which accepted inert waste with no further detail provided. One of the cells is adjacent to the DCO boundary. Due to the nature of the landfill waste infill, the risk of significant contamination associated with the landfill and any leachate is considered unlikely, however it will require confirmation should the proposed slope stabilisation measures comprise drainage solution. In addition, there is an infilled quarry, Birdlip Quarry, within the south-eastern end of the scheme. It was labelled as 'quarries' on the historical plans in the late 1800s/early 1900s but not delineated until the 1970s and labelled as Birdlip Quarry. It is marked as disused in the early 2000s. ES Appendix 9.1 Preliminary sources study report (Document Reference 6.4) reports it be used as a motorcross track with evidence of fly-tipping. There is no information on the infill of this quarry however two historical boreholes completed in 1988 did not encounter made ground or fill materials. It is not classified as a historical landfill on the governmental database. It may be a potential source of contamination.

H.4.1.7 Infilled quarries located within the DCO boundary are considered as a potential source of ground gas. However, these are not within the highway footprint and will continue freely venting to the atmosphere. Considering the nature and occurrence of made ground, no significant gas generation or migration of ground gas within the scheme footprint is likely. The scheme construction will either result in cutting and removal of made ground or construction of an embankment, which in majority parts of the scheme will incorporate a drainage blanket which will dissipate any ground gas rather than result in accumulation. Therefore, it is considered that there is no viable pathway for exposure to ground gas, and therefore it is not considered to present a significant risk. In addition, it is considered that man entry into excavations/confined spaces would be limited and likely to be controlled. Mitigation measures and health and safety risk management typically carried out as part of working in confined spaces would reduce potential risks to maintenance workers.

H.4.1.8 Construction activities may introduce additional sources such as:

- Encountering areas of unexpected/unknown contamination along the proposed scheme.
- Site won or imported fill materials used in the proposed scheme.
- Dust generated during construction from identified and unexpected sources of contamination.

H.4.1.9 Construction activities would be undertaken in line with current best practice and guidance in accordance with ES Appendix 2.1 Environmental management plan (Document Reference 6.4). Construction-related receptors and sources would be managed to negate their impact on the environment. The commitments include:

- A watching brief for the duration of site works in areas of potential contaminated land or groundwater (by a suitably qualified and experienced person).
- An Action Plan for safely dealing with unexpected contamination.
- Environmental monitoring including surface water and ground water monitoring.

H.4.1.10 The re-use of excavated material would be governed by Annex E Materials management plan of ES Appendix 2.1 Environmental management plan (Document Reference 6.4). Sufficient information would be generated to demonstrate that the excavated material has been re-used appropriately, is suitable for its intended use and does not pose a significant risk to end site users or controlled water receptors. Therefore, site won materials are not considered a potential source during operation. However, operational activities would introduce additional sources of contamination. Following the opening of the scheme, soils adjacent to the road may be affected by spray or airborne contaminants generated during routine maintenance and operation of the road including airborne deposition of traffic fumes.

H.4.1.11 Direct discharge of potential contamination into groundwater may occur as a result of accidental spillages and leakages of fuel. This may impact the quality of groundwater, receiving surface water courses and associated water abstraction points. Assessment of drainage impact on water environment is considered in ES Chapter 13 Road drainage and water environment (Document Reference 6.2).

H.4.2 Receptor(s)

H.4.2.1 Based on the current land use the potential receptors of potential contamination have been identified and are listed in Table H-4. Additional potential receptors introduced during the scheme construction or operation are discussed below:

Table H-4 Potential receptors of contamination

Receptors	Descriptions
Human health	
Residents and workers of villages, hamlets, and farms on land parcels adjacent to the scheme	Residents and workers may be impacted by long-term exposure to the potential contamination sources within the scheme area. The nearest residential properties are located on land parcels adjacent to the scheme including Crickley Hill Farm, Crickley Hill residential areas, Air Balloon Cottages, Rushwood Kennels, Shab Hill Farm, Stockwell, Nettleton. These are shown on ES Figure 9.7 Land use features plan (Document Reference 9.3).
Recreational users of new and existing public right of way footpaths (e.g. walkers, cyclists and horse riders and disabled users) in the scheme area and its direct vicinity, including the Air Balloon Way (the repurposed A417)	Due to shorter term exposure durations, it is considered that these receptors are less likely to be impacted. Public right of way footpaths are located in across the study area and are interlinked with the scheme. These are shown on ES Figure 9.7 Land use features plan (Document Reference 9.3).
Highway regular maintenance workers on the existing and new A417	Regular and possible long-term (albeit intermittent) exposure to the potential contamination sources e.g. during grass verge maintenance. The potential risks can be mitigated through a

Receptors	Descriptions
	health and safety management framework e.g. wearing appropriate Personal Protective Equipment (PPE).
Highway construction workers during the new A417 construction and during major intrusive maintenance works during operation	Potentially short term but direct exposure to the potential sources of contamination within the scheme footprint during ground breaking works and earthworks. The potential risks can be mitigated through a health and safety management framework e.g. wearing appropriate PPE.
Motorised users of the existing and new A417 road at tie-in points with the proposed scheme and other roads crossing the proposed scheme	These receptors are considered to be at a low risk due to the transient nature of their likely exposure to the potential contamination sources.
Surface water and groundwater	
Groundwater beneath and outside the scheme study area (Principal and Secondary Aquifers)	Impact from contamination within the footprint of the proposed scheme and off-site migration. Groundwater is considered a sensitive receptor owing to the aquifer designation.
Surface water features within the study area	Identified in Chapter 13 Road drainage and the water environment (Document Reference 6.2).
Water abstraction points within the study area	Identified in Chapter 13 Road drainage and the water environment (Document Reference 6.2).

H.4.2.2 Under the current baseline conditions, nearby residents and workers, recreational users of the study area may be exposed to potential sources of contamination through ingestion, inhalation and dermal contact with soils dust. Exposure to groundwater is unlikely.

H.4.2.3 The scheme will introduce new receptors, site operatives during the scheme construction and new maintenance workers. In addition, the repurposed existing A417 (the proposed Air Balloon Way) will be used by walkers, cyclists and horse riders and disabled users and the scheme will also be interlinked with the existing and new public right of way footpaths e.g. through the proposed Emma's Grove access bridge and Shab Hill underpass.

H.4.2.4 Review of the possible impact on construction and maintenance workers (existing and future) indicates that they are considered the most likely to be impacted by the potential sources of contamination for the following reasons:

H.4.2.5 They may be directly exposed to contaminated soils or made ground on-site during works on the existing infrastructure, particularly during any earthworks. Exposure pathways would include dermal, ingestion and inhalation. The exposure duration is likely to be relatively short-term. Regular maintenance works could be on a regular basis, over the lifetime of the worker (e.g. grass cutting on verges). It is anticipated that construction and highway maintenance workers would be working under a health and safety management framework e.g. wearing appropriate PPE.

- There is a high likelihood of encountering made ground or contaminated soils during the construction and maintenance works within the highway corridor.
- Existing and future motorised users of the A417, and other roads in the study area are unlikely to be impacted by contamination due to the relative isolation within vehicles and their transient nature and likely short-term duration.

H.4.2.6 Environmentally, identified receptors include groundwater resources within underlying Principal and Secondary A aquifers along the alignment and associated water abstraction points and source protection zone, and groundwater fed surface water features such as springs and streams. These are detailed in ES Chapter 13 Road drainage and water environment (Document Reference 6.2).

H.4.3 Pathways

H.4.3.1 The potential pathways identified during review of the baseline scenarios are presented in Table H-5 and additional potential pathway introduced during the scheme construction or operation are discussed below.

Table H-5 Potential pathways for contamination migration

Pathway	Description
Human health	
Ingestion of soil and dust	Exposed soils in temporary excavations e.g. road works/farmland in the immediate vicinity, during cutting of verges.
Inhalation of soil dust	Generation of dust during temporary excavations (e.g. roadworks) or other works such as farming, grass cutting, or from areas at surface without vegetation cover.
Inhalation of volatile organic contamination	Inhalation of vapours from sources e.g. fuel spills/leaks.
Dermal contact with soils and dust	Contact with temporarily exposed site soils (road works/farming) or dust created in excavations.
Surface water and groundwater	
Direct release of contaminants from leaks or spills into controlled waters (e.g. groundwater, streams, springs, rivers)	Leaks or spills near controlled waters, or into drainage which discharge to controlled waters.
Release of contaminants from leaks or spills during road operation into the sub-surface and subsequent vertical and lateral migration through unsaturated and saturated zones	Migration through pore space/fractures in rocks and soils, along preferential pathways such as service corridors or higher permeability strata. Impact on aquifers within subsurface, surface waters through springs/issues.
Leaching of contamination from soils into surface waters, or into the sub-surface and subsequent vertical and lateral migration through unsaturated and saturated zones	

H.4.3.2 In relation to the baseline conditions present along the existing alignment, the most prevalent pollutant linkages are associated with the inhalation of dusts and dermal contact with potential contamination with the receptors being site walkers, cyclists and horse riders and disabled users.

H.4.3.3 Future maintenance workers and construction workers are likely to be directly exposed to contaminated soils or made ground during the works on site through dermal, ingestion and inhalation. Exposure duration is likely to be relatively short-term, however it is feasible that this could be on a regular basis, over the lifetime of a worker (e.g. grass cutting of verges) with a possible exposure to soil dust. It is anticipated that both construction and future maintenance workers will be working under a health and safety management framework and will therefore be wearing appropriate PPE.

H.4.3.4 Deep excavations are unlikely to be part of regular maintenance works, so direct exposure to groundwater is considered unlikely.

H.4.3.5 In relation to controlled waters, with respect to plausible pathways potentially impacting groundwater, it is considered that the leaching of contaminants from site soils as a result of rainwater infiltration is likely in areas of open soft landscaping (new and existing) in the absence of drainage or hard cover. This may also result in mobilisation of contaminates and vertical migration into the underlying groundwater

H.4.3.6 Increased rainwater infiltration into the ground during excavation works or point discharge into the ground of water removed during dewatering activities may result in mobilisation of contaminates and vertical migration into the underlying groundwater.

H.4.3.7 Lateral migration of the impacted groundwater or migration through karts features, towards the surface water receptors.

H.4.3.8 Additionally, due to the nature of previously encountered strata within the available GI (granular materials overlying weathered bedrock), vertical and lateral migration of contamination is considered plausible.

H.4.3.9 The proximity of surface water features in relation to the scheme makes the potential of surface run-off discharge of potential contamination into adjacent surface waters a plausible pathway. The surface water features within close proximity to the scheme are illustrated in ES Chapter 13 Road drainage and water environment (Document Reference 6.2).

H.4.3.10 Drainage associated with slope stability measures may provide new pathways of potential contamination by providing a conduit from potential sources of contamination to surface water/groundwater receptors.

H.4.3.11 The presence of karst enhanced features and gulls and fissures within the rock, particularly in the Crickley Hill escarpment area may provide preferential flow paths for contaminants. Introduction of piled foundations may also create new such pathways.

H.5 Tier 1: Preliminary Risk Assessment

H.5.1.1 In accordance with CIRIA 552[12] , the plausible pollutant linkages within the conceptual site model have been evaluated in the context of risk forming the basis of the preliminary risk assessment. This is shown in Table H-6.

[12] CIRIA (2001), Contaminated land risk assessment- A guide to good practice (C552)

Table H-6 Preliminary Risk Assessment

Potential Source	Potential Receptor	Possible Pathway	Likelihood	Severity	Risk	Comment
Operational Conditions						
On Site **1. Made ground:** *Existing road infrastructure;* *Encountered during completed GIs;* **2. Infilled quarries** *(unknown backfill with potential contamination)* **3. Current or historical activities:** *Possible contamination associated with operation of A417 and other roads crossing the proposed scheme alignment incl. drainage;* *Land use: electricity sub-station, agricultural, etc;* *Previous pollution incidents (recorded and un-recorded);* **Off Site** **1. Made ground:** *Possible made ground associated with the existing road infrastructure in vicinity of the proposed scheme alignment;*	Maintenance workers	Ingestion of soils and dusts	Low likelihood	Mild	Low	Made ground is likely to be present in the scheme area, however soils reuse in accordance with MMP and therefore unlikely to pose a significant risk. Identified contaminated materials within the scheme footprint would be removed as a result of construction. Implementation of a health and safety management framework. Maintenance workers are unlikely to be exposed to ground gas, accumulation of which is unlikely to be occurring. Appropriate use of PPE would be sufficient to eliminate the risks posed by exposure routes. Identification of contaminants of concern required to confirm the risks via investigations and assessments to inform materials management and health and safety.
		Inhalation of soils, and dusts	Low likelihood	Mild	Low	
		Inhalation of gases and volatile organic contamination	Unlikely	Mild	Very low	
		Dermal contact with soils	Likely	Mild	Moderate/low	
	Motorised users of the existing/ proposed scheme;	Ingestion of soils and dusts	Unlikely	Medium	Low	Users of the scheme are unlikely to be exposed to any potential contamination due to a very short-term exposure scenario.
		Inhalation of dusts	Unlikely	Medium	Low	
		Inhalation of gases and volatile organic contamination	Unlikely	Medium	Low	
		Dermal contact with soils	Unlikely	Medium	Low	

Potential Source	Potential Receptor	Possible Pathway	Likelihood	Severity	Risk	Comment
Possible made ground associated with private developments, i.e. farmland. **2. Historical landfill/backfilled quarries:** *Crickley lodge historical landfill used for the disposal of inert waste;* *Backfilled quarries- unknown backfill with potential contamination;* **3. Current or historical activities** *Possible contamination associated with operation of A417 and other roads/highway in vicinity of the scheme alignment;* *Land use- horticulture, agriculture, substations etc;* *Previous pollution incidents (recorded and un-recorded;)* *Soakaway drainage as possible contamination pathways;*	Walkers, cyclists and horse riders and disabled users of Air Balloon Way and off-site public right of way footpaths	Ingestion of soils and dusts	Unlikely	Medium	Low	Made ground is likely to be present in the scheme area, however soils reuse in accordance with MMP and therefore unlikely to pose a significant risk. Identified contaminated materials within the scheme footprint would be removed as a result of construction. Ingestion of soils and dusts are unlikely based on the current conditions of the site and conditions post completion. Although there is a low likelihood, due to the activities associated with rambling, dermal contact with contaminated soils may be possible if contamination persisted near surface if encountered outside the scheme in the wider study area. Identification of contaminants of concern required to confirm the risks via investigations and assessments to inform materials management and remediation requirements, where necessary.
		Inhalation of soils, and dusts	Low likelihood	Medium	Moderate/low	
		Inhalation of gases and volatile organic contamination	Unlikely	Medium	Low	
		Dermal contact with soils	Low likelihood	Medium	Moderate/low	
	Residents and workers of nearby villages, hamlets, and farms in the vicinity of the scheme	Ingestion of soil dusts	Unlikely	Medium	Low	Made ground is likely to be present in the scheme area, however soils reuse in accordance with MMP and therefore unlikely to pose a significant risk. Identified contaminated materials within the scheme footprint would be removed as a result of construction. It is unlikely that adjacent workers and residents will be directly exposed to soils within the scheme area unless as part of activities within the wider study area set out above.
		Inhalation of soil dusts	Unlikely	Medium	Low	
		Inhalation of gases and volatile organic contamination	Unlikely	Medium	Low	
		Dermal contact with soils dust	Unlikely	Medium	Low	

Potential Source	Potential Receptor	Possible Pathway	Likelihood	Severity	Risk	Comment
						Identification of contaminants of concern required to confirm the risks via investigations and assessments to inform materials management and remediation requirements, where necessary
	Groundwater (groundwater in Principal aquifers and Secondary A aquifers) Water Abstraction Points/SPZ	Leaching of contaminants, vertical and horizontal migration within the subsurface or along foundations e.g. piles or services e.g. drainage	Likely	Medium	Moderate	Made ground is likely to be present in the scheme area, however soils reuse in accordance with MMP and therefore unlikely to pose a significant risk. Identified contaminated materials within the scheme footprint would be removed as a result of construction. Migration of contaminants via leaching of soil-based contamination (e.g. in areas of landscaping) is considered plausible, as is downward migration along deep foundations (e.g. piles) or through existing or new infrastructure (e.g. drainage). Identification of contaminants of concern required to confirm the risks via investigations and assessments to inform materials management and remediation requirements, where necessary.
		Direct discharge into the ground	Likely	Medium	Moderate	
	Surface water features	Direct discharge Surface run-off	Likely	Medium	Moderate/ low	Given the distance from the scheme to surface water features, particularly the tributary to Norman's Brook, which is located within the scheme area, it is considered plausible that contamination may migrate into these receptors either via surface run-off, lateral groundwater migration or indirectly through springs. Identification of contaminants of concern required to confirm the risks via investigations and assessments

Potential Source	Potential Receptor	Possible Pathway	Likelihood	Severity	Risk	Comment
						to inform materials management and remediation requirements, where necessary.
Construction Phase						
As above. In addition, areas of unexpected/unknown contamination along the scheme; *Site won, or off-site derived fill materials used in the proposed scheme or taken off-site for disposal (including soils, road planings);* *Imported construction materials e.g. grout, cement;* *Dust generated during construction from areas of made ground, infilled quarries and other contamination;* *Contaminated groundwater encountered during earthworks;*	Construction workers	Ingestion of soils and dusts	Low likelihood	Mild	Low	It is likely that construction workers may come into contact with potentially contaminated soils/materials, primarily through the inhalation of soil dusts and direct dermal contact. Due to the nature of the proposed scheme it is considered unlikely that exposure to ground gas or volatile organic contamination will pose a significant risk. Given the nature of construction, it is anticipated that construction works will be undertaken with a health and safety management plan including the use of appropriate PPE. This is considered sufficient to mitigate the posed risks. Identification of contaminants of concern required to confirm the risks via investigations and assessments to inform materials management and health and safety.
		Inhalation of soils, and dusts	Likely	Mild	Moderate/Low	
		Inhalation of gases and volatile organic contamination	Unlikely	Mild	Very low	
		Dermal contact with soils	Likely	Mild	Moderate/Low	
	Neighbouring residents/ workers, walkers, cyclists and horse riders and disabled users of public right of way	Ingestion of soil dusts	Low likelihood	Medium	Moderate/low	During construction, there is a low likelihood that neighbouring workers/ residents and walkers, cyclists and horse riders and disabled users will be exposed to dust generated from contaminated soils.
		Inhalation of soil dusts	Low likelihood	Medium	Moderate/low	
		Inhalation of gases and volatile organic	Unlikely	Medium	Low	

Potential Source	Potential Receptor	Possible Pathway	Likelihood	Severity	Risk	Comment
	footpaths in the scheme vicinity	contamination				There is a low likelihood that dusts generated during the works may impact the mentioned receptors. Identification of contaminants of concern required to confirm the risks via investigations and assessments to inform materials management and health and safety.
		Dermal contact with soils dust	Low likelihood	Medium	Moderate/low	
	Motorised users of the existing scheme during construction of the new scheme	Inhalation of soil dusts	Unlikely	Medium	Low	During construction, there is a low likelihood associated with dust generated during the works.
		Inhalation of gases and volatile organic contamination	Unlikely	Medium	Low	
	Groundwater (groundwater in Principal aquifers and Secondary A aquifers)	Leaching of contaminants, vertical and horizontal migration within the subsurface	Likely	Medium	Moderate	There is an increased likelihood of contaminants leaching during the construction phase due to open excavations encouraging increased infiltration of rainwater. Identification of contaminants of concern required to confirm the risks via investigations and assessments to inform materials management.
		Direct discharge into the ground	Likely	Medium	Moderate	
	Surface water features	Direct discharge Surface run-off	Low likelihood	Medium	Moderate/ low	Given the distance from the proposed scheme to surface water features, it is considered plausible that contamination may migrate into these receptors either via surface run-off, lateral groundwater migration or through springs. Pollution control measures and permitting requirements for direct discharge are set out in the EMP, as presented in the ES. Identification of contaminants of concern required to confirm the risks via investigations and assessments.

H.6 Tier 2: Generic Quantitative Risk Assessments

H.6.1 Human Health Tier 2 GQRA

Introduction

H.6.1.1 The preliminary risk assessment identified a number of potential receptors during the scheme construction and operation. These are summarised in Table H-7.

Table H-7 Identified receptors and assessment scenarios

Receptors	Descriptions	Assessment scenario
Residents and workers of villages, hamlets, and farms on land parcels adjacent to the scheme	Construction phase	Residential without plant uptake
Recreational users of new and existing public right of way footpaths (e.g. walkers, cyclists and horse riders and disabled users) in the scheme area and its direct vicinity, including the Air Balloon Way (the repurposed A417)	Construction phase Operational phase	Public Open space (park)
Highway regular maintenance workers on the existing and new A417	Operational phase	Commercial
Highway construction workers during the new A417 construction and during major intrusive maintenance works during operation	Construction phase Operational phase	Residential without plant uptake

H.6.1.2 Based on the identified potential receptors, the risk assessment is undertaken by application of generic assessment criteria for commercial, public open space (park) and residential without plant uptake end use scenarios. Additionally, these criteria will also be used to evaluate the chemical suitability for material reuse, in relation to human health, based on the proposals to use site won soils in future earthworks.

H.6.1.3 In the absence of acute exposure generic assessment criteria, the assessment to evaluate the risks posed to construction workers has used the most stringent assessment criteria such as residential without plant uptake.

H.6.1.4 The identified made ground is heterogenous and was encountered in localised areas along the proposed scheme. No distinctive averaging areas of contamination can be identified. In addition, due to the targeted nature of sampling and wide geographical spread of sampling locations, no statistical analysis has been undertaken as the results are unlikely to be representative of a single population. In addition, results are limited per area of identified made ground. Therefore, upon the identification of any exceedances of the applied screening criteria, potential sources associated with the made ground (containing elevated determinands) will be considered on a case by case basis.

H.6.1.5 The Tier 2: GQRA has been informed by the results of chemical analyses completed on 23No. samples obtained from across the A417 alignment. All of the samples obtained for soil dry weight analyses have been sampled from made ground, with no natural samples analysed as part of the assessment.

Results

H.6.1.6 Results of chemical soil testing are summarised in Annex A, Table A-1. The Tier 2: GQRA identified exceedances in the applied assessment criteria, all of which were with respect to PAH compounds. No other exceedances have been identified. No asbestos was identified in the analysed samples.

H.6.1.7 Exceedances were identified in samples obtained from five exploratory holes, as detailed in Table H-8, distributed across the scheme alignment. All of the exceedances are in relation to the applied residential without plant uptake scenario criteria, with the public open space (park) and commercial scenarios criteria exceeded in only one location, DS/RC415. This is discussed in more detail in the following section.

H.6.1.8 The exceedances of PAH compounds concentrations in CP106 coincide with visual/olfactory evidence recorded in the log at the sample location i.e. slag or ash inclusions. Borehole logs for DS/RC415 and DS/RC419 recorded tarmacadam at surface in the investigated locations, which may be a source of the elevated concentrations of PAHs. This is discussed in more detail in the following section. No evidence of contamination was recorded in samples obtained from CP215 and OH415.

Table H-8 Exceedances in the applied assessment criteria

Exploratory Hole ID	Depth of sample (m bgl)	Evidence of contamination	Recorded concentrations above the applied assessment criteria (mg/kg)	Exceeded assessment criteria (mg/kg) / Receptors		
				Residential without plant uptake	Public Open space (park)	Commercial
				Construction scenario (Scheme neighbours and site workers)	Operational scenario (walkers, cyclists and horse riders and disabled users)	Operational scenario (Maintenance workers)
CP106 (Grove Farm/ Crickley Hill Tractors in area of proposed attenuation basin)	1.0	Ashy slag, clinker and concrete inclusions (0-0.4m bgl) Slag, concrete, brick and hydrocarbon odour (0.4 – 0.75m bgl) Slag inclusions (0.75-1.3m bgl and 1.9-2.6m bgl)	B(b)f - 6.9 B(a)p - 5.8 D(a,h)a - 0.69	3.9 5.3 0.31		
DS/RC419 (Barrow wake car park in area of proposed drainage)	0.30-0.50	Tarmacadam (0-0.15 m bgl)	B(b)f - 4.2 D(a,h)a - 0.73	3.9 0.31		
OH405 (Air Balloon PH car park 22m south of area of proposed cut)	0.30-0.40	Brick inclusions (0.15-0.9m bgl)	D(a, h) - 0.34	0.31		
DS/RC415 (Farm access (towards Birdlip) 7m south of proposed Air Balloon Way)	0.60-0.70	Tarmacadam (0.3-0.6 m bgl)	Naphthalene - 21 B(a)a - 39 B(b)f - 41 Chrysene - 35 B(a)p - 34 D(a,h)a - 3.8	2.3 11 3.9 30 5.3 0.31	 13 21 1.1	 3.5
CP215 (Crickley Hill escarpment (southern and northern) middle section area of proposed slope stabilisation)	0.30	Brick and glass inclusions (0.3-0.4m bgl) Brick, concrete and slate (0.4-0.7m bgl)	D(a,h)a - 0.42	0.31		
B(a)a - Benzo(a)anthracene; B(b)f - Benzo(b)fluoranthene; B(a)p - Benzo(a)pyrene; D(a, h)a - Dibenz(a,h)anthracene						

Discussion

H.6.1.9 The Tier 2 risk assessment has identified exceedances in relation to the applied assessment criteria for the three considered exposure scenarios. This has identified potential risks posed during the construction phase to construction workers and scheme neighbours, and during the operational phase to scheme neighbours and users including residents, walkers, cyclists and horse riders and disabled users, and future maintenance workers.

Construction phase

H.6.1.10 A number of exceedances of the applied assessment criteria for PAH compounds have been identified with respect to construction workers and residents of properties on land parcels adjacent to the scheme. A review of the results indicates that the highest concentrations of PAHs in DS/RC415 were measured in a sample obtained from materials directly underlying tarmacadam. Similarly, the sample obtained from DS/RC419 was also obtained from materials underlying tarmacadam. In both cases no other evidence of contamination was recorded. The sampled materials comprised made ground described as dark yellowish brown sandy gravel of limestone or gravelly sand. The laboratory descriptions agree with the exploratory logs. Therefore, it is considered likely that potential cross contamination with broken tarmacadam during sampling may be the source of the identified PAHs in these two samples. The identified exceedances with respect to walkers, cyclists and horse riders and disabled users are all in DS/RC415.

H.6.1.11 Construction activities such as tarmacadam stripping, processing and storage may result in release of dust that may contain elevated concentrations of PAH compounds. The excavation of made ground containing broken and unbound tarmacadam inclusions may also generate dusts and pose a risk to human health during construction and will require appropriate control measures. The chemical testing has indicated that soils impacted by tarmacadam may have limited suitability for reuse. Therefore, during excavations care needs to be taken to separate and segregate tarmacadam from underlying soils.

H.6.1.12 Additionally, ash and slag inclusions identified in the sampled strata in CP106 corresponded with elevated PAHs in made ground. Evidence of potential contamination such ash and/or clinker, and also slag inclusions was recorded across the area of Grove Farm/Crickley Hill Tractors during the historical investigations. No geo-environmental testing was undertaken, however these are likely to be a source of contaminants such as PAHs and metals. Other evidence of hydrocarbon contamination such as odours was also encountered in CP106, which is likely to be a result of current land use due to accidental fuel spillages or leakages. It is considered there is a high likelihood of encountering other areas of hydrocarbon contamination within the area of Grove Farm. This indicates that the infill materials in the area of Grove Farm may pose a risk to human health during construction works and particularly during ground-breaking activities like excavations, which may mobilise the contamination. This will require appropriate control measures.

H.6.1.13 No potential sources of the identified exceedances of dibenz (a, h) anthracene were identified in CP215 and OH405. The sampled soils were described as dark brown sandy gravelly silt or brown gravelly silty clay, respectively, both with inclusions of brick and/or glass. The laboratory descriptions agree with the exploratory logs. This indicates that the made ground materials in the area of Air Balloon car park and northern area of Crickley Hill fields may pose a risk to human health during construction works and particularly during ground-breaking activities like excavations, which may mobilise the contamination. This will require appropriate control measures.

Scheme operation

H.6.1.14 With respect to maintenance workers, a single exceedance has been identified, also in a sample obtained from DS/RC415. Dibenz (a, h) anthracene was measured at a slightly higher concentration than the applied assessment criterion, which is not considered significant. As discussed above it is considered that this exceedance is likely due to tarmacadam inclusions. This may indicate that broken unbound tarmacadam materials may pose a risk and should be considered as part of health and safety risk assessments.

H.6.1.15 The above assessment also showed that tarmacadam materials should they be reused in broken and unbound form as well as soils directly underlying tarmacadam may pose a risk to walkers, cyclists and horse riders and disabled users. Therefore, made ground impacted by tarmacadam may pose a risk to human health during operation if e.g. used at surface in landscaped areas. Therefore, the reuse of tarmacadam impacted materials should be limited to placement at depth e.g. below topsoil.

Conclusions

H.6.1.16 The completed risk assessments have not identified unacceptable risks with respect to the proposed end use. Therefore, no remediation measures are required subject to conclusions of the controlled waters risk assessments. The identified risks can be managed by appropriate health and safety measures and materials management during construction. The completed risk assessments indicate that majority of the soils encountered within the scheme are likely to be suitable for reuse with respect to human health, subject to appropriate verification process.

H.6.2 Controlled Waters Tier 2 GQRA

Introduction

H.6.2.1 The preliminary risk assessment identified surface water and groundwater as sensitive receptors to potential contamination within the scheme area.

H.6.2.2 The assessment of groundwater quality has been undertaken for each hydrogeological unit. Reference should be made to the main report for details on groundwater regime within the scheme area. Based on hydrogeological impact assessment a number of units have been distinguished. These are presented in Table H-9 together with potential interactions with the scheme.

Table H-9 Identified controlled water receptors and potential interaction with the scheme

Hydrogeological unit	Key scheme elements	Surface water receptors
Mass movement deposits (‘head’) in Crickley Hill	Excavations for highway drainage and realigned stream Underpasses	Tributary of Norman’s Brook

Hydrogeological unit	Key scheme elements	Surface water receptors
escarpment area (underlain by the Lias Group)	Slope stabilisation measures	
Lias Group mudstones	None	N/A
Inferior Oolite Group limestone formations and underlying Bridport Sand Formation of the Lias Group	Excavations for cutting Ch 1+800 to 3+000 (eastern end of the cutting only)	Tributary of Norman’s Brook
	Foundations (including piling) for Emma’s Grove access bridge	N/A
Great Oolite Group limestone formations	Excavations for cuttings between Shab Hill and Cowley Junctions Excavations for highway drainage	River Churn catchment in the north River Frome catchment in the south Unlicenced surface water abstractions
Great Oolite Group Fuller’s Earth Formation		
	Foundations (including piling) for overbridges	N/A

H.6.2.3 During construction the scheme is likely to interact with majority of these hydrogeological units during earthworks in areas of with the main cuttings, attenuation basins and associated highway drainage, slope stabilisation measures (including drainage) and other infrastructure, and piling works. Localised dewatering may be required in these areas. Removed groundwater will require discharge, potentially into surface water or ground. In addition, highway drainage will be collecting groundwater, primarily from the Great Oolite Group limestones formations, which will be then discharged into the surface water system. This may pose a risk to the surface water receptors as listed in Table H-9.

H.6.2.4 The assessment of the baseline surface water quality has been undertaken for each surface water catchment as follows:

- Tributary of Norman’s Brook, part of which is within the scheme footprint (sampling point SW2). The stream was also sampled approximately 550m downstream of the scheme footprint, where it daylights from a culverted section (SW1).
- River Frome catchment. Two sampling pints have been established within the scheme vicinity, SW3 on a tributary of the Frome (approximately 330m west of the scheme footprint) and SW4 on the Frome River (approximately 600m south-west of the scheme footprint).
- River Churn catchment. Two sampling points have been established within the scheme vicinity, SW5 on a tributary of the Churn (approximately 1500m east of the scheme footprint) and SW6 on another tributary of the Churn (approximately 2000m south-west of the scheme footprint).

H.6.2.5 The location of the surface water features and the extent of the catchment is shown on ES Figure 13.1 Surface water features and ES Figure 13.8 Catchment abstraction management strategy areas (both Document Reference 6.3). The location of the monitoring points is shown on ES Figure 13.15 Water environment monitoring locations (Document Reference 6.3).

H.6.2.6 Made ground is considered a potential source of contamination with respect to the above listed controlled water receptors. The identified made ground is heterogenous and was encountered in localised areas along the proposed scheme. No distinctive averaging areas of contamination can be identified. Therefore, upon the identification of any exceedances of the applied screening criteria with respect to soil leachate testing, potential sources associated with the made ground have been considered on a case by case basis.

Groundwater Quality Assessment

H.6.2.7 The available groundwater data from completed recent ground investigations have been used to establish baseline groundwater quality and inform the assessment of risk to surface water receptors. This includes 80No. groundwater samples. All of the samples were obtained from installations and were subsequently sent for laboratory testing. The results are summarised in Table A-2 in Annex A. Table H-10 provides a summary of the identified exceedances.

Table H-10 Groundwater exceedances in the applied criteria

Determinant	FEQS or CL:AIRE TPH AC	Identified Exceedances No. exceedances/ No. samples	UK DWS	Identified Exceedances No exceedances/ No sample
Great Oolite Group (limestone formations)				
Copper (bioavailable)	1 µg/l	3 / 14 (1.2 – 3.2 µg/l)	-	-
Manganese (dissolved)	-	-	50 µg/l	1 / 14 (58 µg/l)
Great Oolite Group (Fuller's Earth)				
Naphthalene	2 µg/l	1 / 4 (6.7 µg/l)	-	-
Anthracene	0.1 µg/l	2 / 4 (0.1 – 0.9 µg/l)	-	-
Benzo(a)pyrene	0.00017 µg/l	1 / 4 (0.84 µg/l)	-	-
Fluoranthene	0.0063 µg/l	2 / 4 (0.5 – 3.8 µg/l)	-	-
Total PAH	-	-	0.1 µg/l	2 / 4 (2.6 – 27.3 µg/l)
Manganese (dissolved)	-	-	50 µg/l	1 / 4 (160 µg/l)
TPH Aliphatic C21-C35	-	1 / 4 (350 µg/l)	-	-
TPH Aromatic C12-C16	90µg/l	1 / 4 (300 µg/l)	-	-
Inferior Oolite Group and Bridport Sand Formation of Lias Group				
pH	-	-	6.5-9.5	1 / 13 (12.1)
Aluminium	-	-	200 µg/l	1 / 1 (290 µg/l)
Free cyanide	1 µg/l	1 / 13 (157 µg/l)	-	-
Lead (bioavailable)	1.2 µg/l	1 / 13 (1.39 µg/l)	-	-
Manganese (dissolved)	-	-	50	3 / 13 (83 - 210 µg/l)
Manganese (bioavailable)	123 µg/l	1 / 13 (142.8 µg/l)	-	-

Determinant	FEQS or CL:AIRE TPH AC	Identified Exceedances No. exceedances/ No. samples	UK DWS	Identified Exceedances No exceedances/ No sample
Selenium	-	-	10	1 / 13 (12 µg/l)
Lias Group (mudstones)				
pH	-	-	6.5-9.5	9 / 14 (11.6 - 12.5)
Nitrate	-	-	50 mg/l	1 / 14 (3800 mg/l)
Phenol	7.7 µg/	1 / 14 (1100 µg/l)	-	-
Copper (bioavailable)	1 µg/l	2 / 14 (1.1 – 1.3 µg/l)	-	-
Manganese (dissolved)	-	-	50 µg/l	4 / 14 (110 - 470 µg/l)
Manganese (bioavailable)	123 µg/l	1 / 14 (319.6 µg/l)	-	-
Mercury	0.07 µg/l	2 / 14 (0.14 µg/l)	-	-
TPH Aromatic C16-C21	90µg/l	1 / 14 (200 µg/l)	-	-
Head deposits				
pH	-	-	6.5-9.5	2 / 31 (12.1 - 12.2)
Nitrate	-	-	50 mg/l	1 / 31 (130 mg/l)
Copper (bioavailable)	1 µg/l	2 / 31 (1.8 - 6.02 µg/l)	-	-
Manganese (dissolved)	-	-	50 µg/l	19 / 29 (55 - 1300 µg/l)
Manganese (bioavailable)	123 µg/l	9 / 29 (136 – 883.9 µg/l)	-	-
Nickel (bioavailable)	4 µg/l	2 / 29 (7.1 – 14.2 µg/l)	-	-
TPH Aliphatic C16-C21	10 µg/l (LOD)	3 / 29 (40 - 970 µg/l)	-	-
TPH Aliphatic C21-C35	10 µg/l (LOD)	3 / 29 (1600 - 10000 µg/l)	-	-

General

H.6.2.8 Laboratory testing completed on groundwater samples identified generally neutral pH with localised alkaline conditions (pH up to 12.5) and elevated concentrations of aluminium and manganese across all monitored strata and the scheme. Identified exceedances specific to the monitored hydrogeological units are discussed below.

H.6.2.9 Alkaline pH as primarily recorded in the head deposits and the Lias Group. This is likely to be associated with dissolution of limestone and increased residence time within these strata due to relatively low permeability of these materials.

H.6.2.10 Highly elevated concentrations of manganese have been recorded in all monitored hydrogeological units but most persistently in the head deposits, the Lias Group and the Inferior Oolite Group. The source of elevated manganese concentrations is unclear. The BGS Baseline report on the Great and Inferior

Oolite of the Cotswolds District states manganese levels to be typically undetected with maximum measured at 18ug/l. Measured concentrations in the scheme area are typically greater than that. It is possible that this is due to the scheme being located in the edge zone and being contained in unconfined aquifers, where groundwater chemistry is mostly influenced by agricultural and other local activities. This is also reflected in the elevated concentrations of nitrates measured in the scheme area.

H.6.2.11 As the surface water assessment indicated, no manganese was measured at elevated concentrations in the monitored watercourses. Therefore, a direct discharge of manganese impacted groundwater into the surface water receptors may pose a risk to the aquatic environment.

H.6.2.12 The area immediately south of one of the cells of the historical landfill has not been investigated due to access issues. Therefore, no information is available on groundwater quality within the scheme area, where slope stabilisation measures (drainage) may be introduced. Inert waste is unlikely to pose a significant risk to the environment, however as environmental standards may have changed since the landfills were established there is a potential for groundwater to be impacted by leachate generated from the deposited waste. Confirmation of potential risks would be required.

Great Oolite Group (limestone formations)

H.6.2.13 Six groundwater monitoring installations with response zone in the limestone formations of the Great Oolite Group have been sampled as part of the Phase 2A investigations. Due to insufficient groundwater levels, not all installations were sampled during the scheduled three rounds. In total 14No groundwater samples were obtained and tested.

H.6.2.14 The assessment identified isolated and relatively minor exceedances of the applied assessment criteria for bioavailable copper (FEQS of 1 µg/l), as detailed in Table H-10. No potential sources of contamination have been identified in the vicinity of the monitored installations, where exceedances were identified. These exceedances are not considered to be significant with respect to potential surface water receptors.

H.6.2.15 Groundwater quality monitoring in an installation in a vicinity of the infilled Birdlip Quarry (DS/RC401) did not identify groundwater deterioration.

Great Oolite Group (Fuller’s Earth)

H.6.2.16 Two groundwater monitoring installations (OH416 and OH403) with a response zone in Fuller’s Earth Formation of the Great Oolite Group were sampled and tested on two occasions as part of the Phase 2A investigations.

H.6.2.17 The assessment identified exceedances of FEQS and UK DWS for Polycyclic Aromatic Hydrocarbons (PAH) compounds and elevated concentrations of aromatic compounds in both analysed samples obtained from OH416, as detailed in Table H-10. In addition, petroleum hydrocarbons were measured at elevated concentrations in both installations.

H.6.2.18 The source of the elevated concentrations of PAH compounds and petroleum hydrocarbons in OH416 is unclear. The response zone is between 3 and 5mbgl in the Fuller’s Earth Formation logged as stiff silty clay. Significant migration of hydrocarbon contamination within these deposits would be inhibited therefore the source of these elevated concentrations is likely to be local to the monitored installation. The potential sources include the existing A417 located directly to the north of OH416 and also made ground encountered in DS/RC415, located 10m west of OH416:

- Drainage discharges from the A417 highway may be a potential source. A soakaway chamber is located approximately 40m to the north of the monitoring well. Although the encountered ground conditions in OH416 indicated the presence of cohesive Fuller's Earth materials the soakaway has been discharging into the ground over the years, potentially resulting in a localised impact on groundwater quality.
- Relatively high concentrations of PAH compounds of 617mg/kg (total PAHs) and petroleum hydrocarbons of 2500 mg/kg (total petroleum hydrocarbons) were measured in DS/RC415 at between 0.6 and 0.7m bgl. It is likely that the overlying tarmacadam is a source of the PAH compounds and petroleum hydrocarbons, although accidental fuel spillages or leakages from agricultural machinery may have also occurred. Rainwater infiltration through tarmacadam into the underlying made ground is likely to be limited and therefore significant leaching and migration of hydrocarbons into groundwater is unlikely. In addition, the cohesive Fuller's Earth materials are likely to limit horizontal and/or vertical migration of contaminants and therefore impacts from potential sources would be localised.

H.6.2.19 The scheme proposals are for repurposing the existing A417 into active travel route (the Air Balloon Way) with increased landscaping in the vicinity of OH416. The existing drainage is to remain in place. Although the inflows will be reduced and of better quality, subsequently potentially reducing the contaminants discharge into groundwater, there is a potential risk of ongoing release of contaminants from sediments or soils within the soakaway. Further investigations and assessment would be required to confirm the risks.

H.6.2.20 Although no works are proposed in a direct vicinity of the monitoring installations, the potential impacts on controlled water receptors outside the DCO boundary will however require confirmation.

H.6.2.21 Petroleum hydrocarbons were also detected in DS/RC403 with a response zone from between 0.5m and 4.2m spanning between made ground and the Fuller's Earth Formation. No evidence of hydrocarbon contamination has been identified from a review of the exploratory hole log. The source may be related to the existing A417. The scheme will require installation of new highway drainage outfall within the vicinity of DS/RC403. The identified presence of hydrocarbon contamination will require consideration during scheme construction, particularly should dewatering be required.

Inferior Oolites Group and Bridport Sand Formation

H.6.2.22 Four groundwater monitoring installations with response zones within the Inferior Oolite Group and one in the Bridport Sand Formation have been sampled as part of both Phase 1 and Phase 2A investigations. The assessment identified a number of exceedances with respect to both FEQS and UK DWS.

H.6.2.23 Elevated concentration of free cyanide at 157 µg/l was measured on a single occasion in DS/RC110. This is significantly higher than the applied assessment criterion of 1 µg/l. The exceedance was recorded during the first round of sampling and testing in April 2019. Three subsequent samples obtained in

October and November 2019, and March 2020 showed free cyanide concentrations below laboratory level of detection of 10 μg/l. Therefore, it is not considered representative of groundwater quality at this location.

H.6.2.24 Slightly elevated concentrations of aluminium have been identified in the one sample analysed for aluminium. No sources of aluminium have been identified within the scheme area. In addition, elevated concentrations of aluminium have been identified within the sampled surface water samples across all three monitored catchments (up to 1000 μg/l), indicating it to be representative of general groundwater quality in the region and unlikely to pose a significant risk to surface water receptors.

H.6.2.25 A number of other minor exceedances have been identified in other installations such as lead, pH and selenium. These exceedances were recorded in various installations across the three monitoring rounds and are not considered to indicate significant groundwater contamination or pose a significant risk to surface water receptors.

Lias Group (mudstones)

H.6.2.26 Six groundwater monitoring installations with response zone within the mudstones of the Lias Group have been sampled as part of the Phase 2A investigations. The assessment identified a number of exceedances with respect to both FEQS and UK DWS, majority of which were measured in DS/RC224.

H.6.2.27 Borehole DS/RC224 is located on the southern slope of Crickley Hill escarpment, approximately 270m west of the Barrow Wake car park. The response zone is at between 50 and 70m bgl. The installation intercepts a band of limestone, which is likely to be the source of the monitored water. The measured exceedances are of phenol (1100ug/l), mercury (0.14ug/l) and aromatic petroleum hydrocarbons (200ug/l). Considering the depth of the monitored groundwater and the hydrogeological setting, it is very difficult to identify the catchment of the monitored groundwater or the source of the identified contaminants, which potentially may be located a significant distance away from the monitoring well. Considering the reduced elevation of the monitored limestone band (156.8 – 158.4mOD) it is likely that this groundwater is currently discharging into the tributary to Norman's Brook, possibly as one of the springs identified along that stream. Consequently, it may be impacting the quality of the stream although the stream quality monitoring did not measure discernible concentrations of petroleum hydrocarbons.

Head deposits

H.6.2.28 12No groundwater monitoring installations with response zones in head deposits have been sampled as part Phase 2A investigations. The assessment identified a number of exceedances, mainly with respect to UK DWS for manganese (50 μg/l), with half of analysed samples containing manganese above the applied standard at 55 - 220 μg/l. These were measured mainly in DS/RC205, DS/RC107 and DS/RC108. It needs to be noted that dissolved manganese was measured above the UK DWS in all monitored hydrogeological units.

H.6.2.29 Elevated concentrations of petroleum hydrocarbons were measured in monitoring installation DS/RC229 on three consecutive occasions. Heavy aliphatic fractions with carbon range between C16 and C35 were measured between 1600 and 10000 μg/l. No potential sources of contamination have been identified in the area of DS/RC229 or within the DCO boundary. However, residential properties are located directly to the north-west of the installation and the source of this groundwater contamination may be associated with these properties. The hydrogeological model for the scheme indicates that groundwater may be discharging into the tributary to Norman's Brook. However, the available surface water monitoring has not indicated an impact on the water quality (see subsequent sections). However, installation of horizontal drainage as part of slope stabilisation measures may provide a direct pathway for that contaminated groundwater into the stream. On confirmation of the drainage design, further assessments will be required to address these risks.

Soil leachate quality assessment

H.6.2.30 19No. samples of made ground were subject to 2:1 leachate analysis for general inorganics, phenols (by HPLC), total phenols and heavy metals. The results are presented in Table A-3 in Annex A and the identified exceedances are summaries in Table H-11.

Table H-11 Soil leachate exceedances in the applied FEQS and UKDWS criteria

Determinant	FEQS (2015)	Identified Exceedances (out of 19 samples)	UK DWS (2017)	Identified Exceedances	Location
Sulphate as SO_4	N/A	N/A	250mg/l	1 exceedance (263 mg/l)	CP200 (Fly-up)
Copper (bioavailable)	1µg/l	14 exceedances (1.1 to 6.1 µg/l)	N/A	N/A	Majority of analysed samples, across the scheme
Lead (bioavailable)	1.2µg/l	4 exceedances (1.2 to 3.4µg/l)	N/A	N/A	DS/RC108 and CP106 (Crickley Hill Tractors); CP215 (Dyke)
Manganese (dissolved)	N/A	N/A	50µg/l	4 exceedances (73 to 150 µg/l)	DS/RC108 and CP106 (Crickley Hill Tractors); DS/RC415 (Roman Rd); CP200 (Fly-up)
Nickel (bioavailable	4µg/l	1 exceedance (4.3µg/l)	N/A -	N/A	CP106 (Crickley Hill Tractors);
Zinc (bioavailable)	12.3 µg/l	1 exceedance (13.7µg/l)	N/A	N/A	CP215 (Dyke)

H.6.2.31 The assessment identified a number of exceedances with respect to the applied assessment criteria, mainly with respect to FEQS for copper (1ug/l) within 14 out of 19 analysed samples. As the measured concentrations of dissolved copper were in a similar range and exceedances of the FEQS were identified across the scheme they are unlikely to be associated with a specific source and are likely to be representative of general background conditions and unlikely to pose a significant risk to controlled waters.

H.6.2.32 Minor exceedances in single samples obtained from across the scheme have been identified for sulphate, lead, manganese, nickel and zinc, which are not considered significant with respect to identified receptors. However, some made ground was recorded to exhibit evidence of hydrocarbon contamination, such as ash, slag, clinker, charcoal, tarmacadam or odours, as summarised in Table 4, for which no soil leachate testing has been undertaken. Two groundwater monitoring locations were situated in the area of made ground at Grove Farm, where the majority of identified evidence of contamination was recorded. Groundwater samples obtained from these locations did not contain elevated concentrations of metals or hydrocarbons that could be correlated with leachable metals or evidence of contamination recorded within that area suggesting that the made ground has no significant impact on the groundwater quality in the current setting, where made ground is covered in hardstanding. However, there is a risk that if made ground is reused in landscaped areas or close proximity to surface water receptors, it may pose a risk to controlled waters.

Surface water quality assessment

H.6.2.33 No.34 surface water samples have been collected from the study area derived for the scheme over six rounds of sampling between August and December 2021.The results are presented in Table A-4 in Annex A and the identified exceedances are summaries in Table H-12.

Table H-12 Surface water exceedances in the applied FEQS and UKDWS criteria

Determinant	FEQS and CL:AIRE TPH AC	Identified Exceedances No exceedances/ No sample	UK DWS	Identified Exceedances No exceedances/ No sample
Tributary to Norman's Brook (SW2) – scheme area				
Aluminium	-	-	0.2 mg/l	5 / 5 (0.25 – 0.66 mg/l)
Benzo(a)pyrene	0.00017 µg/l	3 / 4 (0.02– 0.09 µg/l)	-	-
Fluoranthene	0.0063 µg/l	3 / 4 (0.03– 0.1 µg/l)	-	-
Total PAH	-	-	0.1 µg/l	3 / 4 (0.2 – 0.8 µg/l)
Tributary to Norman's Brook (SW1) – downstream of scheme area				
Aluminium	-	-	0.2 mg/l	2 / 5 (0.26 – 0.87 mg/l)
Benzo(a)pyrene	0.00017 µg/l	3 / 5 (0.02– 0.09 µg/l)	-	-
Fluoranthene	0.0063 µg/l	3 / 5 (0.02– 0.11 µg/l)	-	-
Total PAH	-	-	0.1 µg/l	3 / 4 (0.15– 0.86 µg/l)
TPH Aliphatic C16-35	-	1 / 5 (20 µg/l)	-	-
River Frome Catchment (SW3 and SW4)				
Copper (bioavailable)	1 µg/l	1 / 12 (1.7 µg/l)	-	-
Aluminium	-	-	0.2 mg/l	4 / 12 (0.2 – 0.4 mg/l)
Benzo(a)pyrene	0.00017 µg/l	7 / 12 (0.01– 0.06 µg/l)	-	-
Fluoranthene	0.0063 µg/l	8 / 12 (0.02– 0.09 µg/l)	-	-
Total PAH	-	-	0.1 µg/l	6 / 12 (0.13– 0.63 µg/l)
TPH Aliphatic C16-35	-	1 / 12 (12 µg/l)	-	-

Determinant	FEQS and CL:AIRE TPH AC	Identified Exceedances No exceedances/ No sample	UK DWS	Identified Exceedances No exceedances/ No sample
River Churn Catchment (SW5 and SW6)				
Cadmium	0.08 µg/l	1 / 10 (0.7 µg/l)	-	-
Copper (bioavailable)	1 µg/l	1 / 10 (1.7 µg/l)	-	-
Aluminium	-	-	0.2 mg/l	2 / 10 (0.25 – 1 mg/l)
Benzo(a)pyrene	0.00017 µg/l	2 / 9 (0.01– 1.01 µg/l)	-	-
Fluoranthene	0.0063 µg/l	2 / 9 (0.02– 1.14 µg/l)	-	-
Total PAH	-	-	0.1 µg/l	1 / 9 (9.4 µg/l)
TPH Aliphatic C16-35	-	2 / 10 (12 -31µg/l)	-	-

H.6.2.34 The Tier 2: GQRA has indicated that surface water quality is similar in all three monitored catchments, including the tributary of Norman’s Brook, which flows within the scheme area. The assessment identified exceedances of aluminium, PAHs and petroleum hydrocarbons assessment criteria in all catchments and at similar range of measured concentrations. All monitored surface water courses are groundwater fed via springs, from either head deposits, Inferior Oolites Group limestones or Great Oolite Group limestones. However, there is no clear correlation between the quality of monitored groundwater and the quality of the monitored surface water courses. Considering the geographical spread of the monitoring locations and range of measured concentrations, the exceedances are unlikely to be associated with a specific source and are likely to be representative of general background conditions. Agricultural practices and a road network may be the primarily sources of the identified exceedances.

Discussion and conclusions

H.6.2.35 The Tier 2: GQRA has identified a number of exceedances in relation to the controlled water(s) risk assessment, as summarised in Table H-13.

Table H-13 Identified exceedances in the applied FEQS and UKDWS criteria

Controlled waters	FEQS (2015)	UK DWS (2017)	Comment
Groundwater	Copper (bioavailable) Manganese (bioavailable) Lead (bioavailable) Mercury Nickel (bioavailable) Free cyanide PAH compounds TPH Phenol	pH Aluminium Manganese (dissolved) Selenium Total PAHs Nitrate	Generally, no significant exceedances have been identified. The groundwater quality is generally reflective of background and not considered of concern with respect to surface water. This is with an exception of localised elevated TPHs and PAHs, which will require further consideration (listed below), and elevated concentrations of manganese in groundwater, particularly within the head deposits, which may pose a risk to surface water receptors. Although in current conditions no discernible impact on the tributary

Controlled waters	FEQS (2015)	UK DWS (2017)	Comment
			of Norman's Brook has been identified. Consideration of groundwater chemical composition will be required during construction works to inform dewatering activities, where necessary.
Surface water	PAH compounds TPH	Aluminium Total PAHs	Generally, not significant exceedances and not considered of concern. Reflective of general background, no specific sources identified.
Soil leachate	Copper (bioavailable) Lead (bioavailable) Nickel (bioavailable) Zinc (bioavailable)	Sulphate Manganese (dissolved)	Generally, not significant exceedances and not considered of concern. Reflective of general background, no specific sources identified.
Evidence of hydrocarbon contamination	-	-	Primarily encountered in Grove Farm/Crickley Hill and areas of car parking or road network. May pose a risk to controlled waters if reused in landscaped areas or close proximity to surface water receptors or drainage.
Historical landfill cell	Not investigated	Not investigated	May pose a risk to controlled waters if drainage measures are introduced.

H.6.2.36 The Tier 2: GQRA has identified a number of exceedances within analysed samples of groundwater and surface water. The hydrogeological model derived for the scheme, as presented in the Environmental Statement, indicates surface water being recharged by groundwater through springs, particularly the tributary of Norman's Brook in Crickley Hill. Generally, the identified exceedances of the applied assessment criteria in groundwater are not considered significant and the surface water testing results do not indicate the groundwater to have a detrimental impact on surface water quality. However, during construction works site specific consideration of groundwater chemical composition will be required to inform dewatering activities, particularly discharge of removed groundwater, where necessary.

H.6.2.37 The groundwater quality has however been locally impacted by hydrocarbon contamination, PAH compounds and/or petroleum hydrocarbons. In addition, evidence of hydrocarbon contamination has been recorded in made ground encountered in the Grove Farm/Crickley Hill and areas of car parking or road network. In addition, there is a potential risk of the historical landfill cell to be impacting the groundwater quality.

H.6.2.38 The following areas of concern have been identified:

- Area of OH416 and DS/RC415 due to elevated concentrations of PAHs and petroleum hydrocarbons in groundwater and soils, potential sources - existing

A417, accidental fuel spillages or leakages from agricultural machinery. The scheme proposals are for repurposing the existing A417 into an active travel route with increased landscaping in the vicinity of OH416 and DS/RC415. Increased rainwater infiltration may result in mobilisation of contaminants to groundwater. The existing drainage associated with A417 is to remain in place. Although the inflows would be reduced and of better quality, subsequently potentially reducing the contaminants discharge into groundwater, the soakaway may remain an on-going source of contamination. Further assessments to confirm the source and risks is required.

- Area of DS/RC403 due to detected concentrations of petroleum hydrocarbons in groundwater, potential source - existing A417. The scheme proposals are for a new drainage channel to run in a vicinity of DS/RC403. The recorded detectable concentrations of petroleum hydrocarbons may be indicative of a source of hydrocarbon contamination within the area of the scheme. The identified presence of hydrocarbon contamination will require consideration during scheme construction, particularly should dewatering be required. Further assessments to confirm the source and risks is required.
- Area of DS/RC229 due to elevated concentrations of petroleum hydrocarbons in groundwater, potential sources – off-site, not identified, potentially associated with nearby properties e.g. a heating oil storage tank. Installation of horizontal drainage as part of slope stabilisation measures may provide a direct pathway for that contaminated groundwater into the tributary of Norman’s Brook. Further assessments to confirm the source and risks is required.
- Area of Grove Farm due to recorded evidence of hydrocarbon contamination in made ground such as ash, slag, clinker, charcoal or odours. These materials may pose a risk to controlled waters and therefore are not considered suitable for reuse in landscaped areas or in close proximity to surface water receptors.
- Area of the infilled Birdlip Quarry has not been investigated and therefore there is no information on the nature or quality of the fill materials or contamination resulting from the current use as a motorcross track. Further assessments to confirm the source and risks to human health is required.
- Area immediately south of one of the cells of the historical landfill has not been investigated due to access issues and therefore no information is available on groundwater quality within the scheme area. Introduction of the slope stabilisation measures (drainage) may introduce a preferential flow path into the tributary of Norman’s Brook. Further assessments to confirm the source and risks is required.

H.6.2.39 To confirm if these areas of concern pose unacceptable risks a Tier 3: Detailed Quantitative Risk Assessment (DQRA) is required. This would allow to identify and delineate the sources and quantify the risks to identified receptors utilising old and newly gathered data. In outline, the Tier 3: DQRA would include:

- New targeted intrusive ground investigations, with additional soil and groundwater testing targeting areas of concern.
- Further water sampling and testing from identified wells of concern.

H.6.2.40 Based on the results of the Tier 3: DQRA, a remediation strategy would be developed to permanently remove unacceptable risks, if required. Remediation works would typically either remove or reduce the source e.g. excavate impacted made ground or eliminate a pathway e.g. introduce a barrier between the source and a receptor. The remediation strategy would be developed at detailed design and details incorporated into Annex E Materials management plan of ES Appendix 2.1 Environmental management plan (Document Reference 6.4).

H.6.2.41 Remediation works, if required, would be undertaken during construction followed on by a verification process set out in a remediation implementation and verification plan. Discharges resulting from remediation works will be regulated by appropriate environmental permit as detailed in Annex G Ground and surface water management plan of ES Appendix 2.1 Environmental management plan (Document Reference 6.4). Verification may involve monitoring or targeted investigations to confirm that the remediation works have achieved the objectives. On completion of the works, a verification report would be prepared.

Appendix I Geotechnical risk register

Geotechnical risk criteria

						Probability Score				
					Description	Remote	Unlikely	Possible	Likely	Very likely
					Probability (P)	<5%	5-19%	20 – 49%	50 – 74%	>75%
	Description	Time Delay	Cost £	Health and Safety	Environmental	Scale	1	2	3	4	5
Impacts (I)	Very High	>6 months	>£10m	One or more fatalities or major injuries or occupational health conditions resulting in life changing disability.	Significant new or additional permanent adverse environmental effect on the natural or historic environment or a local community. Recurring significant adverse environmental effect or effect on local community requiring remedy or intervention by the Construction Commissioner and/or management by relevant authorities e.g. Local Authority, Environment Agency, Natural England etc. Unanticipated and unmitigated non-compliance with Environmental Minimum Requirements elevated and requiring remedy or intervention from Secretary of State, Parliament or the Courts.	5	5	10	15	20	25
	High	4 to 6 months	>£2.5m - £10m	Single non-life changing injury, occupational health, RIDDOR Reportable Disease / NOID.	Significant new, recurring or additional transient adverse environmental effect or effect on local community requiring remedy or intervention by the Construction Commissioner and/or remedy or intervention by external authorities e.g. Local Planning Authority, Environment Agency, Natural England etc.	4	4	8	12	16	20
	Medium	2 to 4 months	>£1m - £2.5m	RIDDOR reportable injury (>=7 days lost time) or Occupational Health Condition (>=7 days lost time).	Unanticipated adverse transient environmental effect or effect on local community requiring remedy or intervention by Nominated Undertaker and reportable to regulatory authorities.	3	3	6	9	12	15
	Low	1 to 2 months	£100k - £1m	Lost Time Injury (<7 days lost time); or multiple minor injuries; or Occupational Health Condition (<7 days lost time).	Local impact requiring management response, but from which there is natural recovery.	2	2	4	6	8	10
	Very Low	<1 month	<£100k	Injuries requiring first aid treatment or occupational ill- health condition with no lost time.	Minimal environmental impact.	1	1	2	3	4	5

highways england

Note: ~~Strikethrough~~ refers to risks from PCF Stage 2 Preliminary Sources Study Report that are considered closed

Ref no.	Area / Location of risk exposure	Phase of project affected	Hazard description (the cause of a potentially unfavourable event)	Risk Event (Description of the consequences)	Impact description (description of the impact if the hazard is realised)	Pre-mitigation risk L	Pre-mitigation risk I	Pre-mitigation risk R	Proposed mitigation action(s)	Mitigated risk L	Mitigated risk I	Mitigated risk R	Risk owner	Residual Risk
PCF Stage 2 Risks (Preliminary Sources Study Report)														
1		~~Proposed scheme design~~	~~Ground investigation:~~ ~~Access restrictions preclude targeted ground investigation~~	~~Uncertainty in soil parameters used in design leading to either unconservative or over conservative design.~~ ~~Over conservative, i.e. onerous design is proposed to avoid risks derived from the lack of data.~~	~~Increase of construction costs due to a non-optimised design. Uncertainty in likelihood of ground related risks.~~	~~4~~	~~5~~	~~20~~	~~Undertake appropriate GI plan assessment, including land access, ecology and archaeology. It is important to be realistic about the possible limitations. Contingencies must be planned to fill possible information gaps.~~ ~~Undertake appropriate Traffic Management plan assessment.~~ ~~Undertake appropriate GI plan assessment. It is important to be realistic about the possible limitations. Contingencies must be planned to fill possible information gaps.~~ ~~Assume Worst credible design scenario where appropriate in case there is a lack of data.~~ ~~Additional funds to be considered for securing enough road space to~~	~~2~~	~~4~~	~~8~~	~~Highways England~~	Phase 1 and 2A GI substantially completed. Outstanding Phase 2A GI underway and land access agreed. RISK ITEM CLOSED
2		~~Proposed scheme design~~	~~Ground investigation:~~ ~~Poor quality data obtained due to inappropriate performance, incorrect installation, exploratory holes in wrong place, insufficient depth, etc.~~	~~Uncertainty in soil parameters used in design leading to either unconservative or over conservative design.~~ ~~Over conservative, i.e. onerous, design is proposed to avoid risks derived from the lack of~~	~~Increase of construction costs due to a non-optimised design. Uncertainty in likelihood of ground related risks.~~	~~3~~	~~5~~	~~15~~	~~Undertake appropriate GI monitoring and contract with quality assured GI Contractor.~~	~~1~~	~~5~~	~~5~~	~~Highways England~~	Refer to residual risk for risk item 1. Risks identified from findings of GI presented within this risk register from Risk Item 20 onwards RISK ITEM CLOSED
3		Proposed scheme design	Ground investigation: Unknown buried services. Location of utilities not considered in the current supplementary GI proposals - risk of either service or utility strike during GI.	Site personnel injuries.	Health and Safety implications for site personnel. Service strike provoking electrocution, gas explosion, damage to utilities, or other adverse effects. Impact to cost and programme of GI. Increase of costs.	2	5	10	Service plans no older than 6 months old to be obtained for the proposed scheme. GI contractor to implement a safe system of work with site personnel trained and certified in buried service detection to be utilised to scan the ground for buried services prior to breaking ground. Guidance provided in HSG47 to be followed when breaking ground. Ensure latest buried and overhead utility plans are used during design. Use collaborative tools and common data environment to identify clashes with proposed geotechnical works. Most boreholes have had a check done prior to excavation however geophysical methods such as ground penetrating radar (GPR) or electrical resistivity surveying may give a wider picture. Utility plans to be reviewed prior to final schedule 2 issued for tender. All available pre-construction information to be provided in tender for supplementary GI.	1	5	5	Highways England	
4		Proposed scheme design	Ground investigation: Encountering localised contaminated materials.	Illness or injury of site personnel or impact on environmental receptors	Health and Safety implications for site personnel. Additional costs and delays to programme whilst contamination is quantified and remedial measures implemented. Remedial works minimises cross contamination of Principal Aquifer.	2	4	8	Pass all appropriate ground investigation information to the design team and appointed GI contractor. Any visual or olfactory evidence of contamination to be recorded and appropriate personnel notified. Remedial works may be required if contaminated materials are encountered. Appropriate Personnel Protective Equipment (PPE) to be worn at all times. Further GI to consider contaminated land findings from Phase 1 and Phase 2A GIs	1	4	4	Highways England	
5		Proposed scheme design	Environmental constraints: Archaeological constraints including monuments and listed buildings.	Damage to protected historical constructions.	Delay to programme unless identified prior to final route selection.	2	4	8	Consultation with relevant archaeological / trust governing bodies. Proof excavations to occur in selected areas during SI. Record significant places before removal. Risk is delay. (Archaeological findings from PCF Stage 3 to be accounted for in the design and construction)	1	3	3	Highways England	Further archaeology not identified as part of PCF Stage 3 investigation encountered during construction - programme delay
6		Detailed design	Design constraints: Difficulty in accurately characterising a variable weathering profile, especially in the case of the Inferior Oolite Limestones and the Lias Group Formations	Uncertainty in soil parameters used in design leading to either unconservative or over conservative design. Over conservative, i.e. onerous design is proposed to avoid risks derived from the lack of data Potential slope failure for embankment and cutting	Increase of construction costs due to a non-optimised design. Uncertainty in likelihood of ground related risks.	4	3	12	Consider impact of deeper weathered layers on design. Site and structure specific ground models to be prepared. Consider that the main problems will be the cutting and the design of the structures foundations. 'observational approach' adopted for the rock cutting design to help mitigate the risk of local variations including areas of deeper weathering Scope and carry out additional G	2	2	4	Highways England	Risk that weathering profile requires stabilisation measures i.e. soil nails due to poorer materials forming the weathered profile
7		Detailed design	Design constraints: Inability to develop an appropriate groundwater model from lack of groundwater information Insufficient time for groundwater monitoring baseline information	Uncertainty in groundwater and soil behaviour so soil parameters used in design leading to either unconservative or over conservative design Alteration of the existing hydrogeological conditions not acceptable to Environment Agency Over conservative, i.e. onerous design is proposed to avoid risks derived from the lack of data. Negative environmental impact Ecological damage to spring fed environments	Additional costs and delays to scheme with possible review of scheme options Ecological damage is quantified and preventative or remedial measures implemented Increase of construction costs due to a non-optimized design. Uncertainty in likelihood of groundwater related risks. Additional costs and delays in the programme in case underestimation of groundwater conditions In case of negative environmental impact, additional costs due to remedial measures and delay to the programme	3	5	15	Undertake groundwater monitoring as part of GI, including piezometers and water surface features studies to develop a robust hydrogeological model, which is important as the proposed scheme has quite complex groundwater conditions Continue to consult with the Environment Agency Inspections of slopes for seepages to be carried out during investigation. Undertake appropriate design based on groundwater conditions present. Undertake a detailed hydrogeological survey of the site area	2	4	8	Highways England	Findings of groundwater monitoring conducted as part of Phase 1 and Phase 2A GIs reported in Hydrogeological Impact Assessment and summarised in GIR. Conceptual understanding of hydrogeological model has been developed and to form part of Environmental Statement Risk left opened until post DCO

Ref no.	Area / Location of risk exposure	Phase of project affected	Hazard description (the cause of a potentially unfavourable event)	Risk Event (Description of the consequences)	Impact description (description of the impact if the hazard is realised)	Pre-mitigation risk L	Pre-mitigation risk I	Pre-mitigation risk R	Proposed mitigation action(s)	Mitigated risk L	Mitigated risk I	Mitigated risk R	Risk owner	Residual Risk
8		Detailed design	Design constraints: Uncertainty in fault location, nature and extent, especially in the case of the Shab Hill Barn Fault.	Affects rock cutting design and groundwater assessment. Additional costs and Delay of the programme. Structure foundation capacity is affected.	Poor ground conditions and variable permeability. Faulting affects cutting design and land take requirements. Higher permeability along fault zone may either locally extend or shorten the cone of drawdown. Unexpected change in lithology. Settlement and damage of structures, potentially leading to local or global failure Additional cost required to mitigate if foundations affected.	4	3	12	Undertake GI (inclined boreholes or geophysics) to assess location and condition of rock, especially in area of deep cutting and vicinity of structures. Design to include impact of local features in rock mass 'observational approach' adopted for the rock cutting design to help mitigate the risk of local variations including areas of unexpectedly greater fracturing in the vicinity of any faults in the rock cuttings.	2	3	6	Highways England	Location of Shab Hill, Shab Hill Barn Fault and Stockwell Fault determined as part of Phase 2A GI within scheme footprint but residual risk of further faulting not picked up. Observational approach for the cutting design to help mitigate as it allows for areas of greater fracturing to be accommodated (refer to Risk Item 30)
9		Construction	Failure of slopes: Historic landslide with soils of variable composition caused by ground movements. Variable groundwater conditions, with seasonal effects Construction activities, including excavations for earthworks, drainage or structures, instigate failure	Major slope failure on Crickley Hill or lesser failure in Churn valley	Slope movements which require assessment and possible remediation. Damage to scheme construction and surrounding area	5	5	25	Undertake appropriate GI including groundwater monitoring to assess slope stability, employing inclinometers, piezometers, water surface features studies, as well as a geomorphological study, potentially using drone surveys and geophysics (LiDAR) Design to include specification and implementation of stabilisation methods where required Develop stabilisation designs to sufficient extent to allow confirmation that there is sufficient land take allowance in advance of the DCO to provide efficient and effective slope stabilisation design where required	2	5	10	Highways England	Preliminary GIR has considered Phase 2A GI findings on mass movement deposits and presented qualitative risk assessment on wider slope stability around Crickley Hill. Risk Item to remain open and supplemented by Risk Item 26
10		Construction	Failure of existing slopes: Over-steepened rock cutting	Collapse of limestone and reactivation of existing failure planes	Slope movements which could impact on the bypass infrastructure	2	5	10	Undertake appropriate GI, with geomorphological mapping where required, to assess cutting stability. Design to include specification and implementation of stabilisation methods where required Amendments to vertical alignment and reductions in cutting slopes from 60 degrees to overall angles of 35 degrees during Stage 3 design process have significantly reduced this risk.	1	4	4	Highways England	Preliminary GIR has considered Phase 1 and Phase 2A GI findings regarding the rock mass characteristics Risk item to remain open and supplemented by Risk Item 30 and 31
11		Construction	Deformation of the carriageway: Consolidation settlements, in particular beneath large embankments in sensitive soils, soft and compressive soils near surface In cutting variable subgrade conditions, including geological fault, hard ground / obstructions at shallow depth	Long-term settlement causing deformation of carriageway. Settlement of buried services and infrastructure, especially at valley bottom	Deformation of carriageway requiring maintenance action, potentially adjacent to structures	3	4	12	Undertake appropriate GI, including long term performance and attention to faults and rock fissures Design to include specification and implementation of stabilisation methods where required and consideration of interface with structures	1	4	4	Highways England	
12		Construction	Cutting: Design using inappropriate rock mass properties	Over estimate how good the rock mass is. Under conservative assumptions regarding rock behaviour	Health and safety implications for site personnel and end users. Slope failure or collapse - resulting in delays, additional costs, and requirements for remediation works. More land could be required due to instability of vertical slopes, additional damage to the environment provoking additional remedial methods. Additional cost and delays to programme for redesign	3	5	15	Undertake topographic survey of site. Undertake appropriate GI to assess slope stability Design to include slope stability analysis and reinforcement / retaining structures if required	1	5	5	Highways England	Risk item to remain open - to be considered at detailed design
13					Excavatability / rippability of rock - difficult digging conditions not anticipated leading to delays and additional costs. Inappropriate methods used	3	5	15	Undertake appropriate GI to assess ground conditions in existing cuttings Design to include assessment of excavatability. Inspect quarry near Nettleton Bottom. Rock quality may still lead to high construction cost, but quantified at outset	1	5	5	Highways England	Risk item to remain open - to be considered at detailed design
14					Material Classification - incorrectly classified could result in material unsuitable for re-use. Could lead to additional costs for imported material	3	4	12	Undertake GI to assess the geotechnical properties of the strata	1	4	4	Highways England	Risk item to remain open - findings of GIR to be considered at detailed design
15		Construction	Cutting: Weak / weathered rock Variations in groundwater caused by seasonal effects of perched water resulting from variations in slumped areas	Slope failure	Health and Safety implications for site personnel and end users. Reinforcement of Limestone slopes could be required, even requiring additional retaining measures Delay in programme and additional costs. More land could be required due to instability of vertical slopes, additional damage to the environment provoking additional remedial methods and costs	3	5	15	Undertake appropriate GI including groundwater monitoring to assess slope stability, employing inclinometers, piezometers, water surface features studies, as well as a geomorphological study. Design appropriate geotechnical solutions for ground conditions present	1	5	5	Highways England	Risk item to remain open - findings of GIR to be considered at detailed design
16		Construction	Cutting: Soft / unsuitable soils at formation level	Formation level is unsuitable and additional excavating is required	Delay in programme and additional costs	2	3	6	Undertake GI and laboratory testing along the structure location. Design appropriate geotechnical solutions for ground conditions present	1	3	3	Highways England	Risk item to remain open - findings of GIR to be considered at detailed design and supplemented by Risk Item 23, 24, 29 and 36
17		Construction	Structures: Soft / unsuitable soils at foundation level, variable conditions between foundations	Settlement leading to damage of structures. Bearing capacity failure	Health and Safety implications for site personnel and end users. Damage to infrastructure later on in the design life. Local Failure. Increased cost of proposed scheme. Degradation of carriageway / maintenance issues	3	3	9	Undertake GI and laboratory testing along the structure location. Design appropriate foundation solutions for ground conditions present Remove localised areas of soft ground from foundation formations	1	3	3	Highways England	Risk item to remain open - findings of GIR to be considered at detailed design
18		Construction	Structures: Sulphate bearing strata	Aggressive ground conditions for buried concrete	Damage to concrete and failure of foundations. Increased costs to proposed scheme to repair or replace	4	3	12	Undertake chemical testing in accordance with BRE-SD1 during GI. Use appropriate concrete design in construction	1	3	3	Highways England	Risk item to remain open - Assessment in accordance with BRE Special Digest 1 has been undertaken and concrete classification recommendations are presented in the GIR for use in detailed design. Amendment to assessment will however be required following additional GI where there are currently gaps in coverage.
19		Construction	Drainage: Unidentified perched groundwater	Slope failure due to localised feature, especially in area of historic landslide and colluvium	Health and Safety implications for site personnel and end users. Dewatering required during construction. Increased drainage costs	2	4	8	Undertake groundwater survey and monitoring as part of GI Undertake appropriate design based on groundwater conditions present. Undertake a detailed hydrogeological survey of the site area	1	4	4	Highways England	Findings of groundwater monitoring conducted as part of Phase 1 and Phase 2A GIs reported in Hydrogeological Impact Assessment and summarised in GIR. Conceptual understanding of hydrogeological model within mass movement deposits developed. Risk item to remain open and also supplemented by Risk Item 26. Findings to be considered in detailed design

Ref no.	Area / Location of risk exposure	Phase of project affected	Hazard description (the cause of a potentially unfavourable event)	Risk Event (Description of the consequences)	Impact description (description of the impact if the hazard is realised)	Pre-mitigation risk L	I	R	Proposed mitigation action(s)	Mitigated risk L	I	R	Risk owner	Residual Risk
PCF Stage 3 Risks (Geotechnical Interpretative Report)														
20	Site wide	Construction	Contaminated Land Encountering areas not identified as part of Phase 1 and Phase2A GIs during construction or contamination within areas of identified contaminated land not considered a risk (i.e. Grove Farm development platform)	Construction workers exposed to contaminated material during works Material not suitable for reuse - off site disposal may be required	Delay to construction programme to ensure appropriate H&S protocols in place and to remove/treat material Off site disposal increase construction cost	4	1	4	CEMP and protocol to deal with contaminated land to be developed in detailed design and applied during construction	4	1	4	Contractor	
21	0+000 to 0+500	Detailed design	Insufficient ground investigation to characterise ground model for slope stability and embankment design	Cut slope instability beyond area of mass movement deposits caused by Lias Group close to ground surface below Cheltenham Sands And Gravel	Slacker slopes required to maintain stability that may impact on red line boundary or alternative slope stabilisation i.e. gravity retaining wall	4	2	8	Ground investigation required for detailed design to check assumptions presented in GIR and apply findings to detailed design Scope of additional ground investigation defined in updated Annex A addendum	3	2	6	Designer	Additional GI findings suggest material strength is weaker than anticipated and slacker slopes required or alternative stabilisation measures
22			Insufficient ground investigation to characterise ground conditions for material reuse	Cheltenham Sands and Gravels potential higher moisture contents and require treatment (drying) prior to reuse	Delay to construction programme	2	2	4	Ground investigation required for detailed design to check assumptions presented in GIR and apply findings to detailed design Scope of additional ground investigation defined in updated Annex A addendum	1	2	2	Designer	
23			Insufficient ground investigation to characterise ground conditions for pavement subgrade	Cheltenham Sands and Gravels and underlying Lias Group has potential to be high plasticity that may result in CBRs<2.5%	Subgrade treatment required that has construction cost and programme impact	3	2	6	Ground investigation required for detailed design to check assumptions presented in GIR and apply findings to detailed design Scope of additional ground investigation defined in updated Annex A addendum	3	1	3	Designer	During construction areas of subgrade below required CBR could still ne encountered
24	0+500 to 1+600	Detailed design and construction	Soft ground near existing Norman's Brook	Instability and settlement of proposed embankment - impact on construction workers and plant (short term stability) and differential movement of embankment causing settlement of pavement, road furniture and spur drainage	Construction costs associated with ground treatment of soft soil	3	3	9	Soft soil likely to be localised around Normans Brook but not fully delineated. Further GI may help delineate extent or probing prior to construction to assess extent Scheme proposals such that embankments may extend over the soft soil and stability risk reduced	3	2	6	Designer / Contractor	
25		Construction	Soft ground near existing Norman's Brook	Removal of material prior to infilling with drainage fill causes increased unsuitable material and potential instability of existing southern slopes	Increased construction cost for disposal of unsuitable material and increase to programme due to "staged" construction along the existing Norman's Brook	3	2	6	Development of construction methodology to reduce impact on stability during clearance. Stockpiling and testing of excavated material to assess if suitable to re-use as landscape fill or general fill	3	1	3	Contractor	
26	0+500 to 1+750	Construction and operation	Marginally stable wider slopes along Crickley Hill valley	Potential for reactivation of existing and development of new slip surfaces within the Mass Movement Deposits (MMD) triggered by rainfall or other development on the wider slopes	Potential for slip material to impact Cold Slad Lane and potentially part of the eastbound carriageway by the northern slopes or blockage of the relocated Norman's Brook by slip debris from the wider southern slopes	4	5	20	Triggers for potential failures have been interpreted to be largely a result of groundwater fluctuations in response to high rainfall events. PCF Stage 3 has allowed for horizontal slope drainage along the northern slopes to control groundwater/pore water pressures and prevent these building up locally within the slopes . These measures are assumed to be limited to within 50m of the scheme, where the slope movement risk from landslips and material runoff that could potentially impact the scheme are greatest. The mitigation is not intended to improve stability of the wider slopes beyond this 50m buffer but instead to limit risks to the scheme for the more significant risks identified Where no mitigation for southern slopes proposed (Ch 0+500 to 0+820 and Ch 1+050 to 1+700) - it is recommended that periodic inspections and potential clearance of slip material within the relocated tributary of Norman's Brook be included in the maintenance plan	4	3	12	Designer / Contractor / Highways England	Groundwater conditions within wider slopes are highly variable and difficult to predict due to the controlling nature of the more granular blocks and lenses of material sourced from the Inferior Oolite and Bridport Sands within the MMD. Locally porewater pressures will build up where groundwater is confined by more cohesive materials in the slopes. Effectiveness of drainage will need further consideration at detailed design, e.g. potentially quite closely spaced drains will be required to ensure effective risk mitigation Maintenance of drainage required and risk that drainage becomes blocked faulty Agreement of level of risk required with Highways England. Potential for removal of drains and potentially the use of a slope monitoring system to mitigate risk, or even no specific additional risk mitigation measures being required. (Note that there have historically been no failures impacting the highway reported for the current A417 alignment)
27	1+700 to 1+750	Construction and operation	Rockfall observed on existing rock cutting slopes on east bound northern slopes	Rockfall from slope during construction or operation reaching the highway	Impact from rockfall striking construction workers or road users	4	3	12	Scaling during the works to be considered at detailed design and methodology developed for construction. Slope inspections to be incorporated as part of scheme operational phase to identify areas requiring treatment	2	3	6	Designer / Contractor	
28	1+700 to 1+750	Detailed design	Gap in ground investigation over the westbound slope - uncertainty on thickness of MMD and depth to Lias Group (Bridport Sands Formation)	Cutting widening may cause instability within MMD in slope face and Bridport Sands Formation towards the base of the cut	Impact of slip debris on construction workers and road users Increase in construction costs for stabilisation measures	3	4	12	Detailed design ground investigation required to infill gap in information and detailed mapping of existing cut slope (potential traffic management and slope access procedures required) Design to consider use of stabilisation measures i.e. soil nails within slope	2	3	6	Designer / Contractor	The proposed design involves the widening of existing cutting at the same level, i.e. deeper excavations are not proposed. There have been no known reported/identified issues with the existing slope - This will need to be confirmed as part of detailed mapping
29			Gap in ground investigation over the westbound slope - uncertainty on depth to Lias Group (Bridport Sands Formation) at base of cut	Weaker material and water bearing strata within the base and formation of the cut	Groundwater overwhelms road drainage Weaker pavement subgrade then anticipated - increased cost for subgrade treatment	2	3	6	Detailed design ground investigation required to infill gap in information and detailed mapping of existing cut slope (potential traffic management and slope access procedures required) Scope of additional ground investigation defined in updated Annex A addendum	2	2	4	Designer	The proposed design involves the widening of existing cutting at the same level, i.e. deeper excavations are not proposed. There have been no known reported/identified issues with the existing slope - This will need to be confirmed as part of detailed mapping
30	1+750 to 2+100 2+800 to 3+000	Detailed design and construction	Rock quality of Inferior Oolite Group forming cuts variable with reduced quality approaching Shab Hill Fault	Proposed cutting slopes require modification due to excess rock fall / slope failure or longer term rockfall reaching highway	Rock failure debris impacting construction workers or road users Flattening of slope to stable angle (impacting red line boundary) or incorporation of stabilisation measures (rock fall mesh, rock bolts)	4	3	12	Rock slopes have been slackened to overall angles of 35 degrees, mitigating the risk that red line boundary will be inadequate. Findings of GIR to be used in detailed design - rock quality noted to reduce towards Shab Hill Fault 'Observation method' to slope cutting angle within a defined range of enveloped profiles to be considered in detailed design to allow localised modification of the cut slope face to suit rock quality encountered. Rock catch wall to be incorporated	4	2	8	Designer	Quality of rock face to degrade over time and general appearance will change - approach to design and maintenance to be agreed with Highways England
31			Voids / solution features larger than anticipated within Inferior Oolite Group	Voids/solution features within: - cut slope causing instability - cut formation	Rock instability striking construction workers or plant toppling into voids/solutions in cut formation Increase in construction cost to delay with voids/solution features and delay to programme	2	3	6	Observational approach with contingency measures such as dentition/void infill to be developed at detailed design and adopted into construction methodology Details for infill and bridging of voids in formation to be developed	2	2	4	Designer / Contractor	
32			Thickness of Head Deposits/Weathered rock varies and thicker than anticipated	Slope instability of material at top of cut	Slip debris strikes construction workers or road users Flattening of upper slope or stabilisation if excessively thick	3	3	9	Findings from GIR to be adopted in detailed design to incorporate thicker areas of weathered rock Observational approach to be developed as part of detailed design and construction in addition to contingencies if material thicker than anticipated	3	2	6	Designer	
33	2+100 to 2+800 A437	Detailed design	Gap in ground investigation - incomplete scope of Phase 2A GI	Rock quality unknown for cutting design	PCF Stage 3 rock cutting slopes unsuitable and flattening or stabilisation required	3	3	12	Findings of completed Phase 2A to be incorporated as an update to the GIR and to be used in detailed design	2	3	6	Designer	Findings of the completed Phase 2A GI may suggest poorer material than anticipated - modification of PCF Stage 3 cut slope design
34	3+100 to 3+500	Detailed design and construction	Mass movement deposits within the Churn Valley thicker than anticipated	Slope instability during construction due to ground treatment of mass movement deposits and construction of embankment and bridge	Toppling of plant and impact to construction workers due to slope failure of valley sides or failure of embankment during construction	3	3	9	Ground treatment to be designed towards toe of embankment within valley axis to reduce instability risk Construction methodology to be developed associated with treatment of slip material on side slopes i.e. excavation and replacement in bays if required	2	3	6	Designer	

Ref no.	Area / Location of risk exposure	Phase of project affected	Hazard description (the cause of a potentially unfavourable event)	Risk Event (Description of the consequences)	Impact description (description of the impact if the hazard is realised)	Pre-mitigation risk			Proposed mitigation action(s)	Mitigated risk			Risk owner	Residual Risk
						L	I	R		L	I	R		
35	3+500 to 5+500	Detailed design and construction	Upper part of Fuller's Earth Formation weathered to high plasticity clay - moisture susceptible	Impact on material reuse from cutting: - higher moisture content zones impacting material reuse - wetting up of stockpiled material or material placed rendering upper surface unsuitable	Increased volume of unsuitable material that will require treatment (drying / lime addition) for reuse or require disposal off site - impact on construction cost and possible delay to programme	4	1	4	As part of construction protection of stockpiles and formations required to avoid excessive wetting up. Potentially programme works in drier months	3	1	3	Designer / Contractor	
36			Upper part of Fuller's Earth Formation weathered to high plasticity clay - moisture susceptible	Pavement subgrade <2.5%	Treatment of pavement subgrade required (lime) or alternative pavement thicknesses - impact on construction cost and possible programme delays	4	2	8	Findings of GIR to be used in detailed design to delineate areas of higher risk cuttings and further detailed design GI to provide further information with lime addition tests - findings can inform construction costs	4	1	4	Designer	
37			Upper part of Fuller's Earth Formation weathered to high plasticity clay - low strength surfaces	Cutting slope instability along low strength zones and where limestone overlying FEF potential reactivation of previous shear surfaces	Failure during construction or operation - slip mass strikes construction workers or road users - construction cost increase	4	4	16	PCF Stage 3 design to adopt 1:3 slopes with bench at 5m height to prevent cut instability - detailed design to incorporate findings of GIR to confirm proposed slope stability adequate Observational method to be adopted as part of cut construction to assess cut face conditions - alternative stabilisation i.e. soil nails may be required	2	4	8	Designer	
38			Limestone (Great Oolite Group) in areas potentially present towards top of cut	Possible rock fall risk	Rock fall striking construction workers or road users	2	4	8	PCF Stage 3 design to adopt 1:3 slopes with bench at 5m height - rock fall not likely to drop from face due to slope angle - to be confirmed at detailed design Observational method to be adopted as part of cut construction to assess cut face conditions - scaling of face required	1	4	4	Designer	
39	1+000	Construction	Bat Underpass Structure Foundation within embankment and partially on mass movement deposits	Reactivation of slip surfaces in mass movement deposits during construction	Failure of earthworks and wider slope causing slip material to impact construction workers - delay to programme and cost	2	4	8	Construction sequence of embankment to ensure filling up to level of culvert foundation prior to placement on mass movement deposits Monitoring of mass movement deposits during works - no works during extended period of rainfall	2	3	6	Contractor	
40	1+725	Detailed design and construction	Grove Farm Underpass Northern entry to structure requires retaining wal within mass movement deposits	Reactivation of slip surfaces in mass movement deposits during construction and operation	Failure of earthworks at entry point causing slip material to impact construction workers and potentially road users - delay to programme and cost	4	4	16	Stabilisation of cut slope in the form of bored pile retaining wall will need to be considered at detailed design in addition to construction sequence to avoid mobilisation of mass movement deposits	2	4	8	Designer	
41	2+000	Detailed design and construction	Cotswolds Way crossing - potential presence of dissolution voids, which are more prevalent towards the base of the Birdlip Limestone Formation will however need to be considered at detailed design stage	Presence of voids in foundation formations may require treatment Risks to groundwater quality and drainage flow paths if concrete/grout used to treat voids	Potential impacts on hydrogeological regime Potential impacts on groundwater quality Delays to construction programme	3	4	12	Plan for treatment and prepare standard details for this. Treatment of voids using mass concrete or gravel if risks to groundwater quality/flow paths where voids are encountered in excavation formations Any works to be undertaken in accordance with Karst Protocol	2	2	4	Designer	
42	3+200	Detailed design and construction	Shab Hill Junction Underbridge varying abutment foundation conditions due to the Churn Valley Fault crossing under the structure	Differential settlement across the structure due to varying ground conditions or poorer quality rock due to greater fracturing in the vicinity of the fault	Impact on structure differential settlement - impact on construction and maintenance costs	4	2	8	Structure design to adopt additional GI findings and findings of GIR to inform foundation design for the abutments - piled foundations for each abutment may be required	4	1	4	Designer	
43	4+040	Detailed design and construction	Cowley Overbridge Gap in Phase 2A ground investigation - no GI specifically at structure location	Uncertain ground conditions	Risk of over conservative designs being required Risk of ground risks not been considered and issues with bridge performance	3	4	12	Undertake additional Ground Investigation Scope of additional ground investigation defined in updated Annex A addendum	2	2	4	Designer	
44	Site wide	Detailed design and construction	Land contamination assessments identified areas of concern, which may require remediation.	Extent and duration of remedial works uncertain. Long term verification minitoring post remediation. Prolonged regulatory approval.	Potential impact on detailed design solution (stabilisation of slopes) Potential impact on programme and cost	3	4	12	Further investigations and assessments to confirm the risks at detailed design. If required, develop remediation strategy and implementation plan. Further targeted investigations during construction to inform the remedial works. Verfication plan and report. Liaison with regulatory bodies.	3	2	6	Designer / Contractor	

Appendix J Drawings

Name	Title	Revision
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000001	Exploratory Hole Location Plan, Sheet 1 of 6	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000002	Exploratory Hole Location Plan, Sheet 2 of 6	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000003	Exploratory Hole Location Plan, Sheet 3 of 6	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000004	Exploratory Hole Location Plan, Sheet 4 of 6	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000005	Exploratory Hole Location Plan, Sheet 5 of 6	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000006	Exploratory Hole Location Plan, Sheet 6 of 6	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000007	Geological Long Sections - Mainline, Sheet 1 of 4	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000008	Geological Long Sections - Mainline, Sheet 2 of 4	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000009	Geological Long Sections - Mainline, Sheet 3 of 4	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000010	Geological Long Sections - Mainline, Sheet 4 of 4	C01
HE551505-ARP-VGT-X_ML_A417_Z-DR-G-000011	Geological Long Sections - B4070	C01
HE551505-ARP-HGT-X_XX_XXXX_X-DR-LE-000001	Reinterpreted Geology Map, Sheet 1 of 2	C01
HE551505 -ARP-HGT-X_XX_XXXX_X-DR-LE-000002	Reinterpreted Geology Map, Sheet 2 of 2	C01
HE5 51505-ARP-EGT-X_XX_XXXX_X-DR-G-000017	Geotechnical Site Walkover Location Plan, Sheet 1 of 3	C01
HE551505 -ARP-EGT-X_XX_XXXX_X-DR-G-000018	Geotechnical Site Walkover Location Plan, Sheet 2 of 3	C01
HE551505 -ARP-EGT-X_XX_XXXX_X-DR-G-000019	Geotechnical Site Walkover Location Plan, Sheet 3 of 3	C01
HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000001	Slope Zone 6, Geomorphological Map	C01
HE551505 -ARP-EGT-X_XX_XXXX_X-DR-G-000002	Slope Zone 5, Geomorphological Map	C01
HE551505 -ARP-EGT-X_XX_XXXX_X-DR-G-000003	Slope Zone 4, Geomorphological Map	C01
HE551505 -ARP-EGT-X_XX_XXXX_X-DR-G-000004	Slope Zone 3, Geomorphological Map	C01
HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000005	Slope Zone 2, Geomorphological Map	C01
HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000014	Slope Zone 1, Geomorphological Map	C01
HE551505-ARP-EGT-X_XX_XXXX_X-DR-G-000015	Slope Zone 7, Geomorphological Map	C01
HE551505 -ARP-EGT-X_XX_XXXX_X-DR-G-000016	Shab Hill, Geomorphological Map	C01

DO NOT SCALE

Millimetres 0 10 100

LEGEND

- HISTORICAL BOREHOLE
- HISTORICAL TRIAL PIT
- BOREHOLE - PHASE 1
- BOREHOLE - PHASE 2A
- CPT - PHASE 2A
- TRIAL PIT - PHASE 2A
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- 1 - - - - 1 GEOPHYSICAL SURVEY LINES

KEYPLAN

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE TO THE DESIGN HAZARD LOG).

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability	A3
Drawing Status	STAGE COMPLETED

ARUP

Client

highways england

Project Title
A417 MISSING LINK

Drawing Title
EXPLORATORY HOLE LOCATION PLAN
SHEET 1 OF 6

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB

Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number
HE PIN | Originator | Volume
HE551505 - ARP - VGT
X_ML_A417_Z - DR - G - 000001
Location | Type | Role | Number

Revision
C01

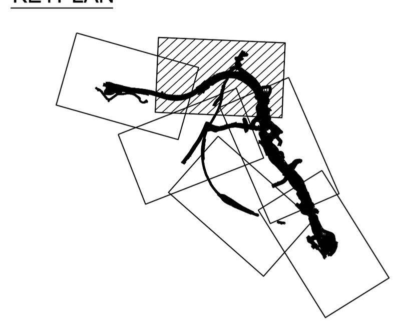
DO NOT SCALE

Millimetres 0 10 100

LEGEND

- HISTORICAL BOREHOLE
- HISTORICAL TRIAL PIT
- BOREHOLE - PHASE 1
- BOREHOLE - PHASE 2A
- CPT - PHASE 2A
- TRIAL PIT - PHASE 2A
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- GEOPHYSICAL SURVEY LINES

KEYPLAN



SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

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CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability	A3
Drawing Status	STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: EXPLORATORY HOLE LOCATION PLAN SHEET 2 OF 6

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB

Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE PIN HE551505 - Originator ARP - Volume VGT
X_ML_A417_Z - DR - G - 000002 (Location, Type, Role, Number)

Revision: C01

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LEGEND

- HISTORICAL BOREHOLE
- HISTORICAL TRIAL PIT
- BOREHOLE - PHASE 1
- BOREHOLE - PHASE 2A
- CPT - PHASE 2A
- TRIAL PIT - PHASE 2A
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- 1 - - - - 1 GEOPHYSICAL SURVEY LINES

KEYPLAN

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CONSTRUCTION: NONE

MAINTENANCE / CLEANING: NONE

USE: NONE

DECOMMISSIONING / DEMOLITION: NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability: A3 — Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: EXPLORATORY HOLE LOCATION PLAN SHEET 3 OF 6

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB
Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE551505 - ARP - VGT - X_ML_A417_Z - DR - G - 000003 (HE PIN | Originator | Volume | Location | Type | Role | Number)

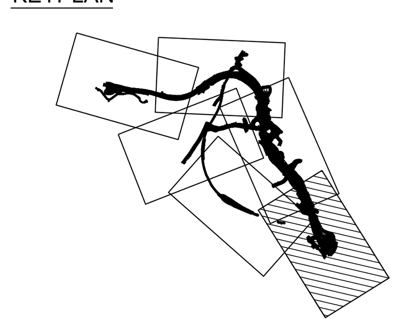
Revision: C01

DO NOT SCALE

LEGEND

- HISTORICAL BOREHOLE
- HISTORICAL TRIAL PIT
- BOREHOLE - PHASE 1
- BOREHOLE - PHASE 2A
- CPT - PHASE 2A
- TRIAL PIT - PHASE 2A
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- GEOPHYSICAL SURVEY LINES

KEYPLAN



SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

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CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability: A3 | Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: EXPLORATORY HOLE LOCATION PLAN SHEET 4 OF 6

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB
Original Size: A1	Date: 21/05/21	Date: 21/05/21	Date: 24/05/21	Date: 24/05/21

Drawing Number: HE551505 - ARP - VGT - X_ML_A417_Z - DR - G - 000004 (HE PIN / Originator / Volume / Location / Type / Role / Number)

Revision: C01

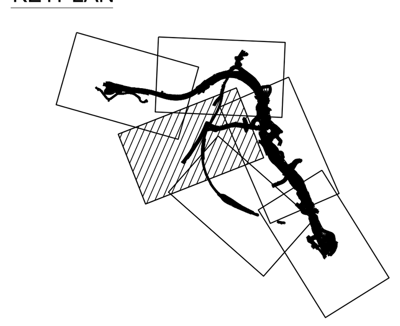
DO NOT SCALE

Millimetres 0 10 100

LEGEND

- HISTORICAL BOREHOLE
- HISTORICAL TRIAL PIT
- BOREHOLE - PHASE 1
- BOREHOLE - PHASE 2A
- CPT - PHASE 2A
- TRIAL PIT - PHASE 2A
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- 1 - - - - 1 GEOPHYSICAL SURVEY LINES

KEYPLAN



SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

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CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability: A3 | Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: EXPLORATORY HOLE LOCATION PLAN SHEET 5 OF 6

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB

Original Size	Date	Date	Date	Date
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Drawing Number: HE551505 - ARP - VGT - X_ML_A417_Z - DR - G - 000005 (HE PIN | Originator | Volume | Location | Type | Role | Number)

Revision: C01

DO NOT SCALE

Millimetres 0 10 100

LEGEND

- HISTORICAL BOREHOLE
- HISTORICAL TRIAL PIT
- BOREHOLE - PHASE 1
- BOREHOLE - PHASE 2A
- CPT - PHASE 2A
- TRIAL PIT - PHASE 2A
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- GEOPHYSICAL SURVEY LINES

KEYPLAN

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

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CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability	A3
Drawing Status	STAGE COMPLETED
Project Title	A417 MISSING LINK
Drawing Title	EXPLORATORY HOLE LOCATION PLAN SHEET 6 OF 6

ARUP

Client: highways england

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB

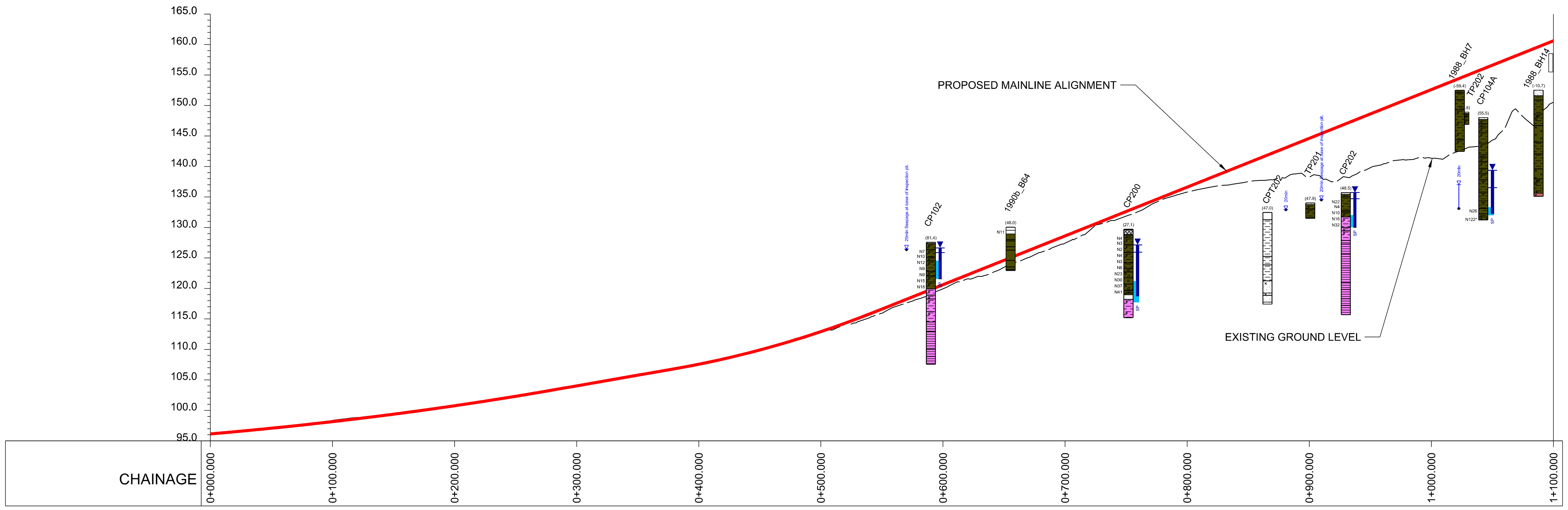
Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE551505 - ARP - VGT - X_ML_A417_Z - DR - G - 000006 (HE PIN | Originator | Volume | Location | Type | Role | Number)

Revision: C01

DO NOT SCALE

PLAN
SCALE 1:2500



PROFILE
SCALE 1:2500H, 1:500V

LEGEND

- HISTORICAL GI
- PHASE 1 GI
- PHASE 2A GI
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- GEOPHYSICAL SURVEY LINES
- GROUNDWATER RISE
- GROUNDWATER STRIKE

MATERIALS

- CLAY
- SILT
- SILTSTONE
- Made Ground - FILL
- GRAVEL
- SANDSTONE
- LIMESTONE
- MUDSTONE
- COBBLES and BOULDERS
- SAND
- BOULDERS

COLOUR LEGEND

- Topsoil [TOPS]
- Made Ground [MG]
- Head Deposits [HDD]
- Landslide Deposits [SLIP]
- Landslide Deposits - Lias Group [SLIP_LIAS]
- Hampen Formation [HMB]
- White Limestone Formation [WHL]
- Salperton Limestone Formation [SALS]
- Aston Limestone Formation [ASLS]
- Birdlip Limestone Formation [BLPL]
- Bridport Sand Formation [BDS]
- Whitby Mudstone Formation [WHM]
- Marlstone Rock Formation [MRB]
- Dyrham Formation [DYS]
- Charmouth Mudstone Formation [CHAM]
- Fuller's Earth Formation [FE]

GENERAL NOTES:

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.
2. ONLY WRITTEN DIMENSIONS SHALL BE USED, DO NOT SCALE.
3. NUMBERS ON BOREHOLE STICKS REPRESENT SPT 'N' VALUES.
4. FOR DETAILED MATERIAL TYPE DESCRIPTIONS REFERENCE SHOULD BE MADE TO THE PHASE 1 AND PHASE 2A FACTUAL GROUND INVESTIGATION REPORTS.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

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CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: GEOLOGICAL LONG SECTIONS MAINLINE SHEET 1 OF 4

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB

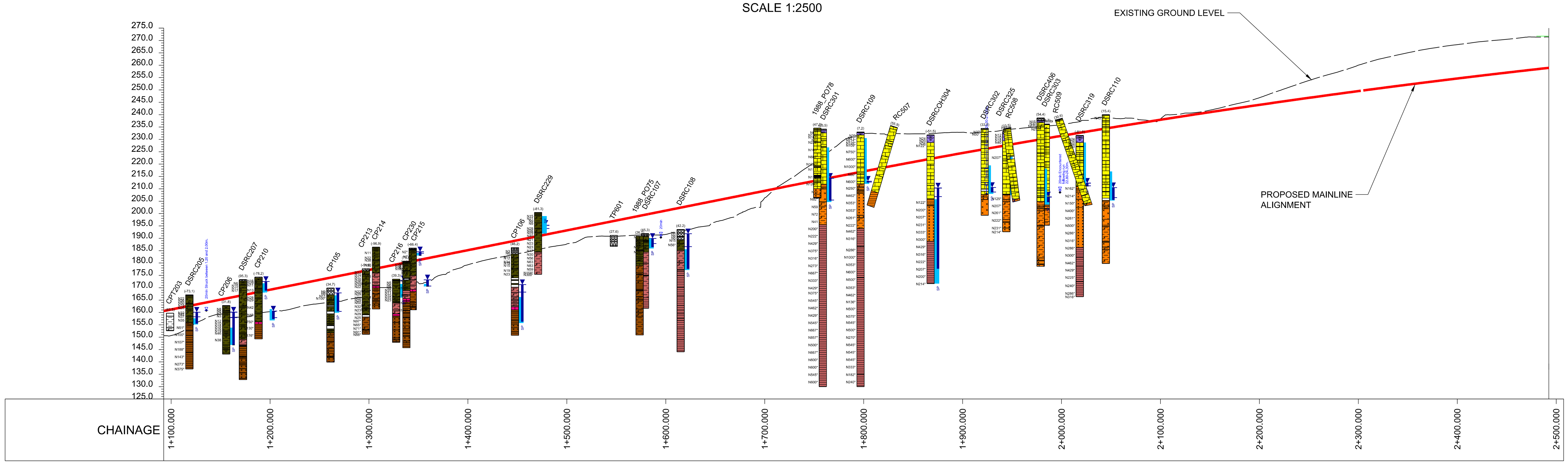
Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE551505 - ARP - VGT - X_ML_A417_Z - DR - G - 000007
Revision: C01

DO NOT SCALE

PLAN

SCALE 1:2500



PROFILE

SCALE 1:2500H 1:1000V

LEGEND

- HISTORICAL GI
- PHASE 1 GI
- PHASE 2A GI
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- GEOPHYSICAL SURVEY LINES
- GROUNDWATER RISE
- GROUNDWATER STRIKE

MATERIALS

- CLAY
- SILT
- SILTSTONE
- Made Ground - FILL
- GRAVEL
- SANDSTONE
- LIMESTONE
- MUDSTONE
- COBBLES and BOULDERS
- SAND
- BOULDERS

COLOUR LEGEND

- Topsoil [TOPS]
- Made Ground [MG]
- Head Deposits [HDD]
- Landslide Deposits [SLIP]
- Landslide Deposits - Lias Group [SLIP_LIAS]
- Hampen Formation [HMB]
- White Limestone Formation [WHL]
- Salperton Limestone Formation [SALS]
- Aston Limestone Formation [ASLS]
- Birdlip Limestone Formation [BLPL]
- Bridport Sand Formation [BDS]
- Whitby Mudstone Formation [WHM]
- Marlstone Rock Formation [MRB]
- Dyrham Formation [DYS]
- Charmouth Mudstone Formation [CHAM]
- Fuller's Earth Formation [FE]

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3. NUMBERS ON BOREHOLE STICKS REPRESENT SPT 'N' VALUES.
4. FOR DETAILED MATERIAL TYPE DESCRIPTIONS REFERENCE SHOULD BE MADE TO THE PHASE 1 AND PHASE 2A FACTUAL GROUND INVESTIGATION REPORTS.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

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CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability: A3 | Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: GEOLOGICAL LONG SECTIONS MAINLINE SHEET 2 OF 4

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB
Original Size	**Date**	**Date**	**Date**	**Date**
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE551505 - ARP - VGT - X_ML_A417_Z - DR - G - 000008 (HE PIN | Originator | Volume | Location | Type | Role | Number)

Revision: C01

DO NOT SCALE

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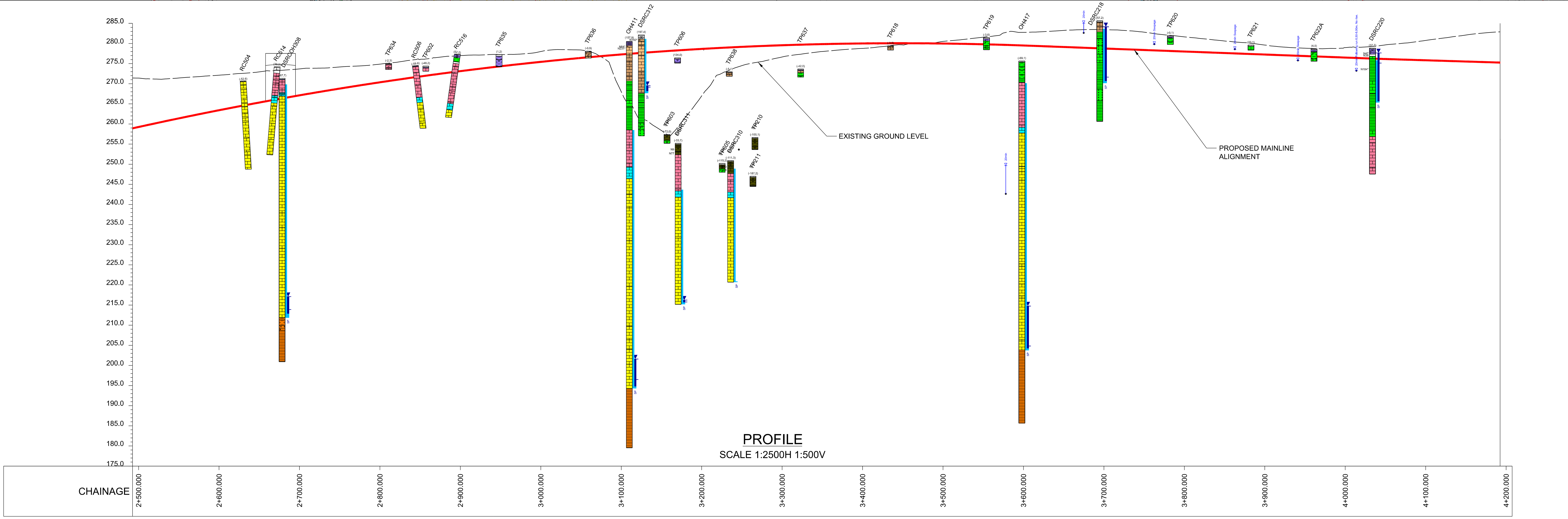

LEGEND

- HISTORICAL GI
- PHASE 1 GI
- PHASE 2A GI
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- GEOPHYSICAL SURVEY LINES
- GROUNDWATER RISE
- GROUNDWATER STRIKE

MATERIALS

- CLAY
- SILT
- SILTSTONE
- Made Ground - FILL
- GRAVEL
- SANDSTONE
- LIMESTONE
- MUDSTONE
- COBBLES and BOULDERS
- SAND
- BOULDERS

COLOUR LEGEND

- Topsoil [TOPS]
- Made Ground [MG]
- Head Deposits [HDD]
- Landslide Deposits [SLIP]
- Landslide Deposits - Lias Group [SLIP_LIAS]
- Hampen Formation [HMB]
- White Limestone Formation [WHL]
- Salperton Limestone Formation [SALS]
- Aston Limestone Formation [ASLS]
- Birdlip Limestone Formation [BLPL]
- Bridport Sand Formation [BDS]
- Whitby Mudstone Formation [WHM]
- Marlstone Rock Formation [MRB]
- Dyrham Formation [DYS]
- Charmouth Mudstone Formation [CHAM]
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3. NUMBERS ON BOREHOLE STICKS REPRESENT SPT 'N' VALUES.
4. FOR DETAILED MATERIAL TYPE DESCRIPTIONS REFERENCE SHOULD BE MADE TO THE PHASE 1 AND PHASE 2A FACTUAL GROUND INVESTIGATION REPORTS.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

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CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: GEOLOGICAL LONG SECTIONS MAINLINE SHEET 3 OF 4

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB
Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE551505 - ARP - VGT - X_ML_A417_Z - DR - G - 000009 (HE PIN | Originator | Volume | Location | Type | Role | Number)

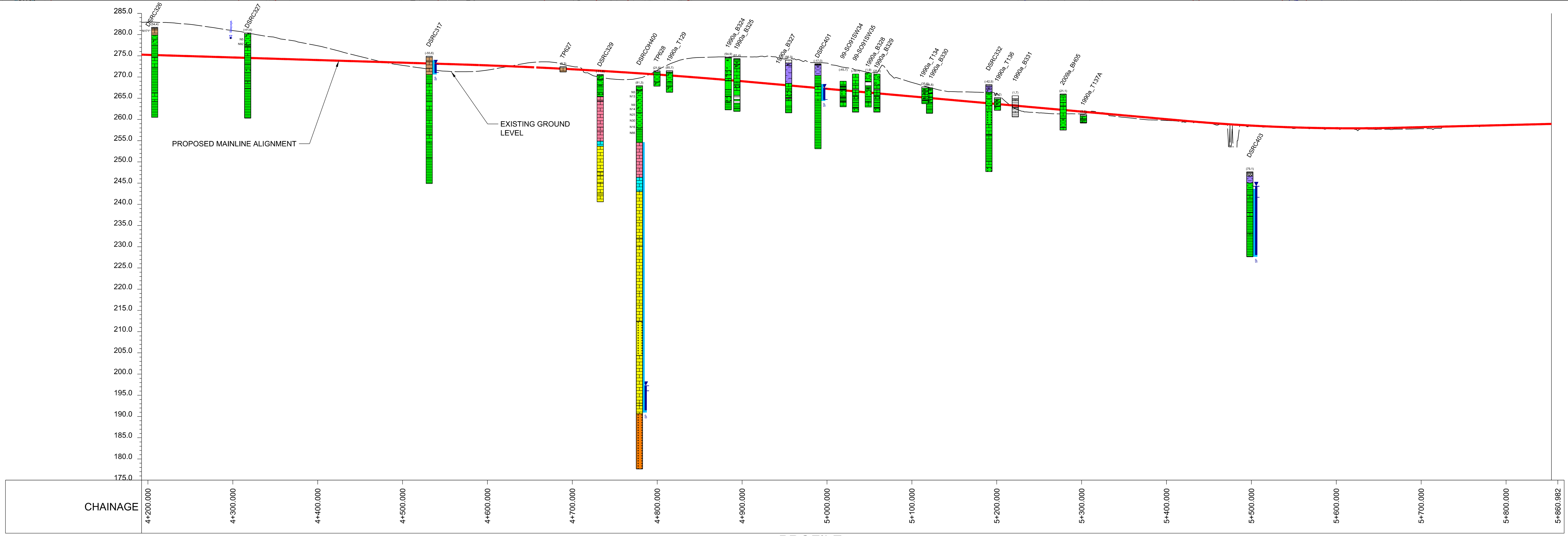
Revision: C01

DO NOT SCALE

Millimetres

PLAN

SCALE 1:2500



PROFILE

SCALE 1:2500H, 1:500V

LEGEND

- HISTORICAL GI
- PHASE 1 GI
- PHASE 2A GI
- PROPOSED SCHEME BOUNDARY
- EXISTING WATERCOURSE
- PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
- PROPOSED CULVERT
- EM SURVEY AREAS
- GEOPHYSICAL SURVEY LINES
- GROUNDWATER RISE
- GROUNDWATER STRIKE

MATERIALS

- CLAY
- SILT
- SILTSTONE
- Made Ground - FILL
- GRAVEL
- SANDSTONE
- LIMESTONE
- MUDSTONE
- COBBLES and BOULDERS
- SAND
- BOULDERS

COLOUR LEGEND

- Topsoil [TOPS]
- Made Ground [MG]
- Head Deposits [HDD]
- Landslide Deposits [SLIP]
- Landslide Deposits - Lias Group [SLIP_LIAS]
- Hampen Formation [HMB]
- White Limestone Formation [WHL]
- Salperton Limestone Formation [SALS]
- Aston Limestone Formation [ASLS]
- Birdlip Limestone Formation [BLPL]
- Bridport Sand Formation [BDS]
- Whitby Mudstone Formation [WHM]
- Marlstone Rock Formation [MRB]
- Dyrham Formation [DYS]
- Charmouth Mudstone Formation [CHAM]
- Fuller's Earth Formation [FE]

GENERAL NOTES:

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.
2. ONLY WRITTEN DIMENSIONS SHALL BE USED, DO NOT SCALE.
3. NUMBERS ON BOREHOLE STICKS REPRESENT SPT 'N' VALUES.
4. FOR DETAILED MATERIAL TYPE DESCRIPTIONS REFERENCE SHOULD BE MADE TO THE PHASE 1 AND PHASE 2A FACTUAL GROUND INVESTIGATION REPORTS.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE TO THE DESIGN HAZARD LOG).

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability	Drawing Status
A3	STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: GEOLOGICAL LONG SECTIONS MAINLINE SHEET 4 OF 4

Scale	By	Checked	Approved	Authorised
1:2500	ES	IE	JP	YB

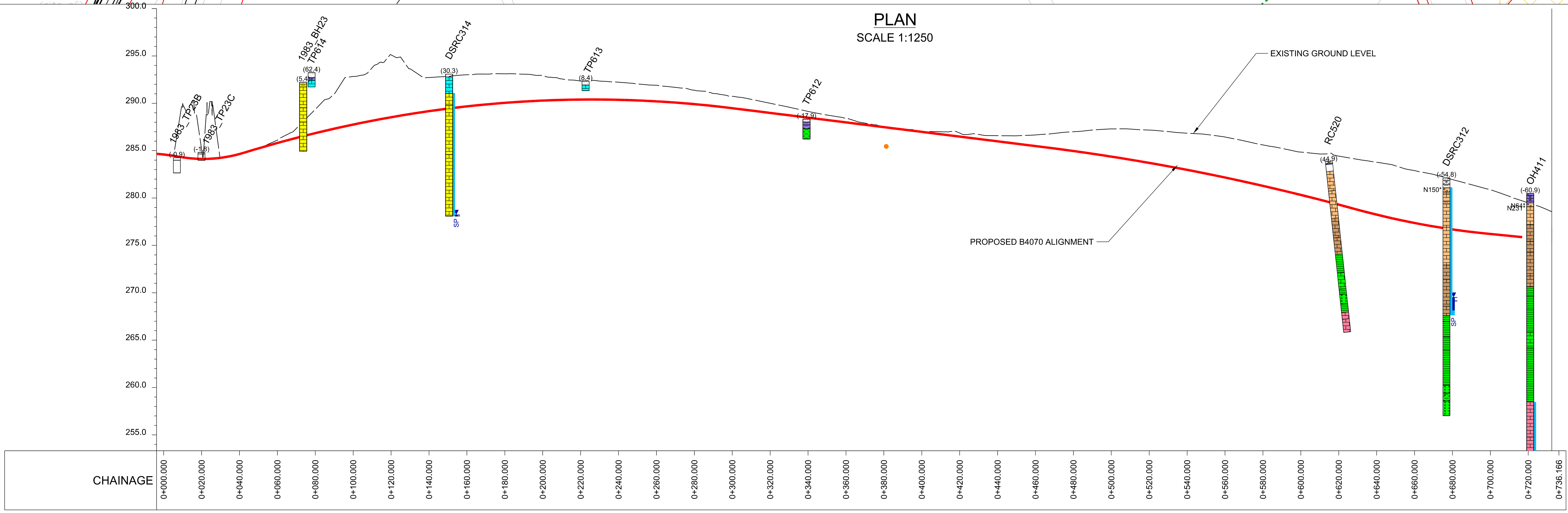
Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE PIN HE551505 - Originator ARP - Volume VGT X_ML_A417_Z (Location) - DR (Type) - G (Role) - 000010 (Number)

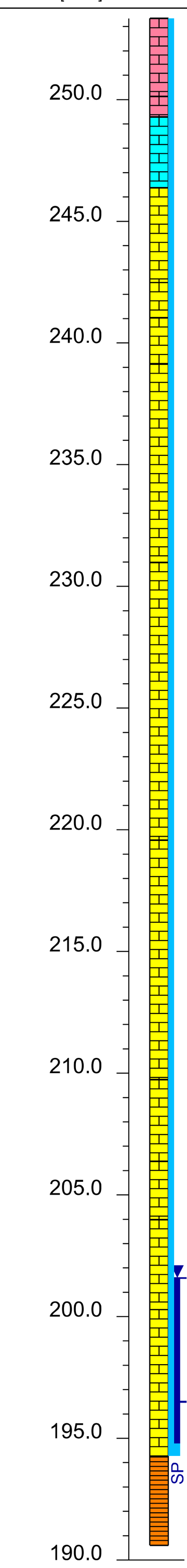
Revision: C01

DO NOT SCALE

PLAN
SCALE 1:1250



PROFILE
SCALE 1:1250H, 1:250V



OH411 (CONTINUED)
SCALE 1:1250H, 1:250V

LEGEND
HISTORICAL GI
PHASE 1 GI
PHASE 2A GI
PROPOSED SCHEME BOUNDARY
EXISTING WATERCOURSE
PROPOSED WATERCOURSE DIVERSION/OVERLAND FLOW DITCH
PROPOSED CULVERT
EM SURVEY AREAS
GEOPHYSICAL SURVEY LINES
GROUNDWATER RISE
GROUNDWATER STRIKE

MATERIALS
CLAY
SILT
SILTSTONE
Made Ground - FILL
GRAVEL
SANDSTONE
LIMESTONE
MUDSTONE
COBBLES and BOULDERS
SAND
BOULDERS

COLOUR LEGEND
Topsoil [TOPS]
Made Ground [MG]
Head Deposits [HDD]
Landslide Deposits [SLIP]
Landslide Deposits - Lias Group [SLIP_LIAS]
Hampen Formation [HMB]
White Limestone Formation [WHL]
Salperton Limestone Formation [SALS]
Aston Limestone Formation [ASLS]
Birdlip Limestone Formation [BLPL]
Bridport Sand Formation [BDS]
Whitby Mudstone Formation [WHM]
Marlstone Rock Formation [MRB]
Dyrham Formation [DYS]
Charmouth Mudstone Formation [CHAM]
Fuller's Earth Formation [FE]

GENERAL NOTES:
1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.
2. ONLY WRITTEN DIMENSIONS SHALL BE USED, DO NOT SCALE.
3. NUMBERS ON BOREHOLE STICKS REPRESENT SPT 'N' VALUES.
4. FOR DETAILED MATERIAL TYPE DESCRIPTIONS REFERENCE SHOULD BE MADE TO THE PHASE 1 AND PHASE 2A FACTUAL GROUND INVESTIGATION REPORTS.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION
IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE TO THE DESIGN HAZARD LOG).
CONSTRUCTION
NONE
MAINTENANCE / CLEANING
NONE
USE
NONE
DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	24/05/21	APPLICATION SUBMISSION (MAY 2021)	ES	IE	JP	YB

Suitability: A3 | Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

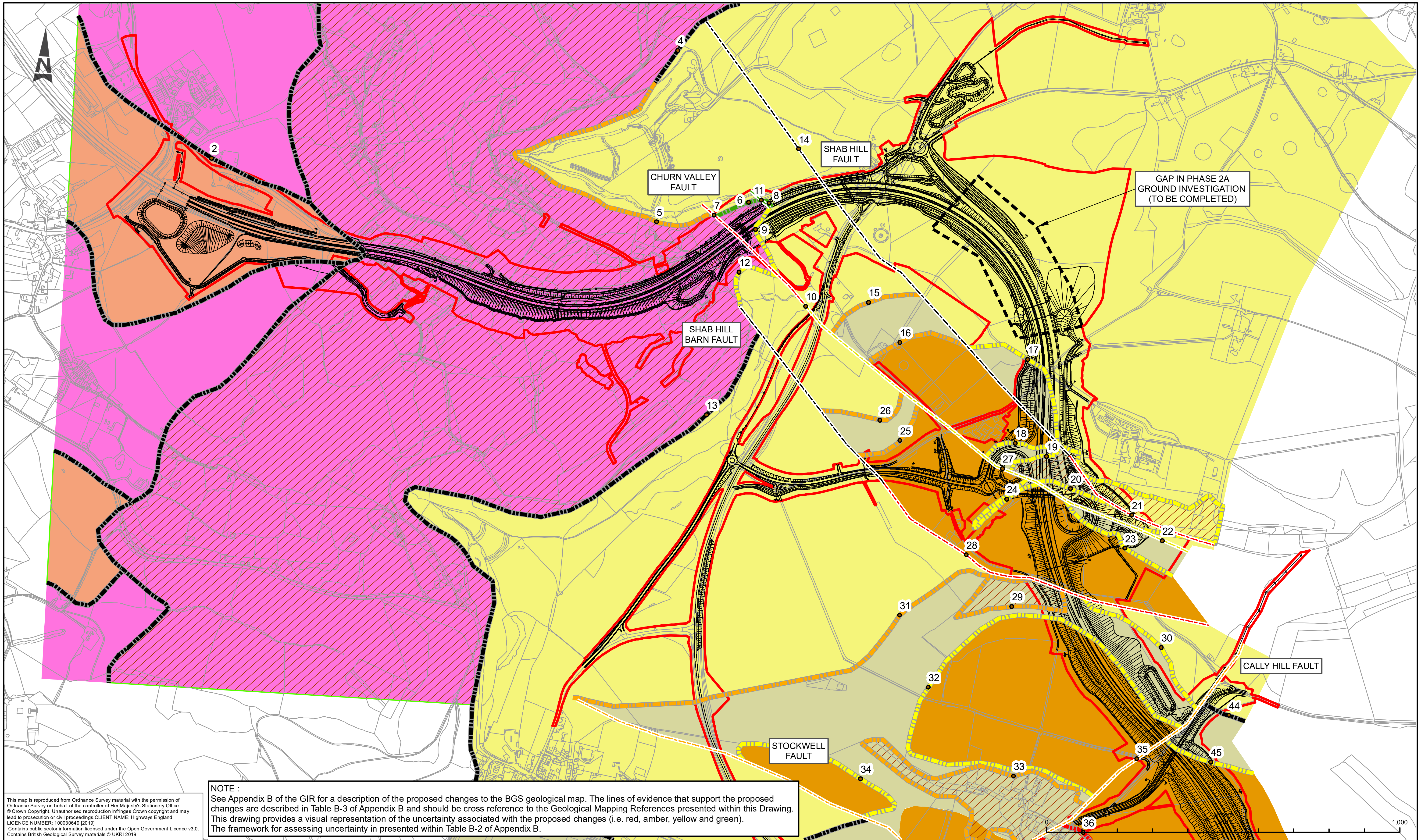
Project Title: A417 MISSING LINK

Drawing Title: GEOLOGICAL LONG SECTIONS B4070

Scale	By	Checked	Approved	Authorised
1:1250	ES	IE	JP	YB
Original Size	Date	Date	Date	Date
A1	21/05/21	21/05/21	24/05/21	24/05/21

Drawing Number: HE PIN HE551505 - Originator ARP - Volume VGT - Location X_ML_A417_Z - Type DR - Role G - Number 000011

Revision: C01



NOTE :
See Appendix B of the GIR for a description of the proposed changes to the BGS geological map. The lines of evidence that support the proposed changes are described in Table B-3 of Appendix B and should be cross reference to the Geological Mapping References presented within this Drawing.
This drawing provides a visual representation of the uncertainty associated with the proposed changes (i.e. red, amber, yellow and green).
The framework for assessing uncertainty in presented within Table B-2 of Appendix B.

LEGEND

- DCO BOUNDARY
- GEOLOGICAL BOUNDARY - NO CHANGE - BASED ON BGS MAPPING
- GEOLOGICAL BOUNDARY - GREEN LEVEL CONFIDENCE (HIGH)
- GEOLOGICAL BOUNDARY - YELLOW LEVEL (MODERATELY HIGH)
- GEOLOGICAL BOUNDARY - AMBER LEVEL CONFIDENCE (MODERATE)
- GEOLOGICAL BOUNDARY - RED LEVEL CONFIDENCE (LOW)
- FAULT - NO CHANGE - BASED ON BGS MAPPING
- FAULT - GREEN LEVEL CONFIDENCE (HIGH)
- FAULT - YELLOW LEVEL CONFIDENCE (MODERATELY HIGH)
- FAULT - AMBER LEVEL CONFIDENCE (MODERATE)
- FAULT - RED LEVEL CONFIDENCE (LOW)
- MASS MOVEMENT DEPOSITS
- CHELTENHAM SAND AND GRAVEL
- LIAS GROUP
- INFERIOR OOLITE GROUP
- FULLER'S EARTH FORMATION
- GREAT OOLITE GROUP FORMATION (LIMESTONE)
- GEOLOGICAL MAPPING REFERENCE (SEE APPENDIX B, TABLE B-3 FOR DETAILS)

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	20/05/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

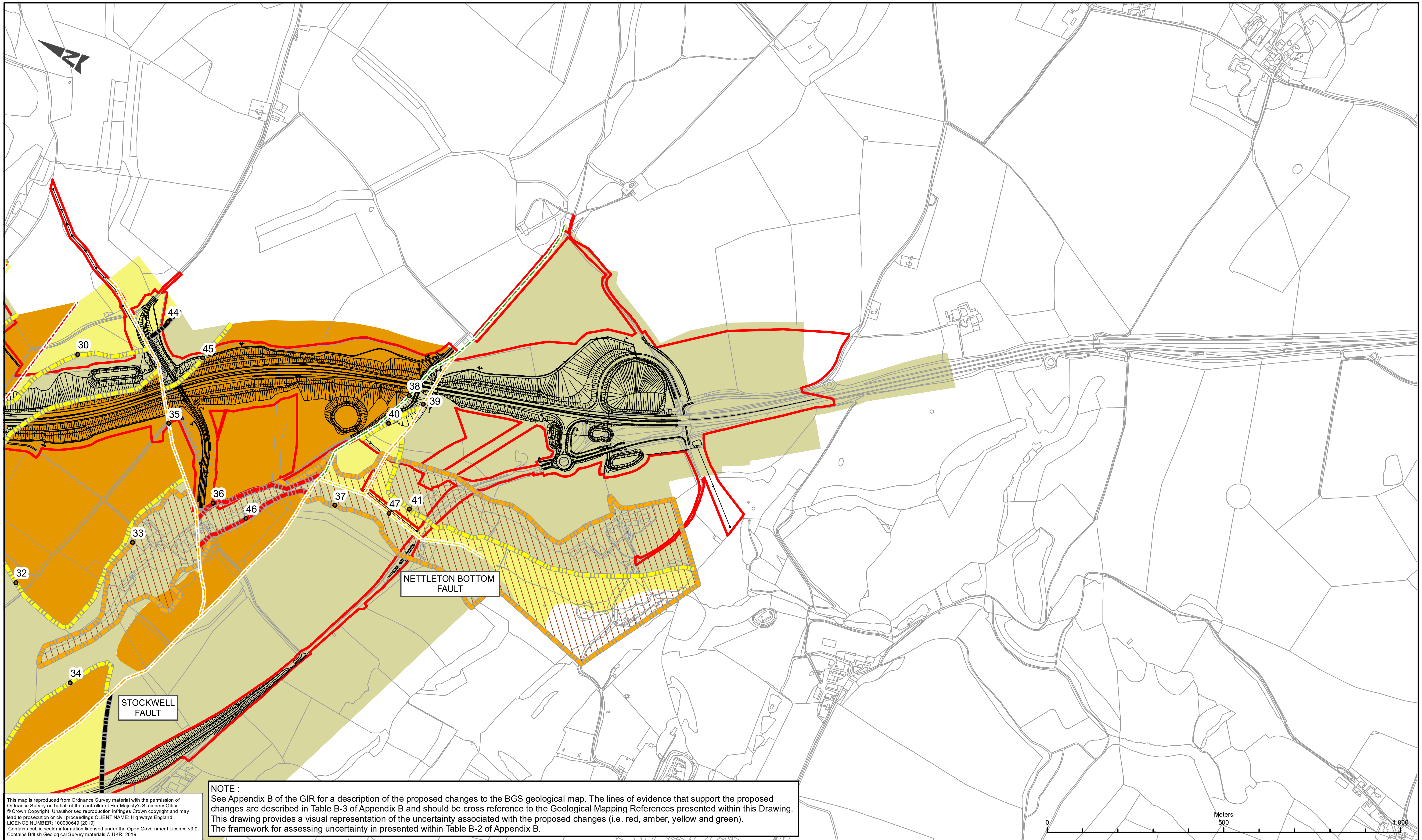
Drawing Title: REINTERPRETED GEOLOGY MAP' SHEET 1 OF 2

Scale	By	Checked	Approved	Authorised
1:10,000	EB	LT	DR	SW

Original Size	Date	Date	Date	Date
A3	20/05/21	20/05/21	20/05/21	20/05/21

Drawing Number: HE551505 - ARP - HGT X_XX_XXXX_X - DR - LE - 000001 (HE PIN | Originator | Volume | Location | Type | Role | Number)

Revision: C01



NOTE :
See Appendix B of the GIR for a description of the proposed changes to the BGS geological map. The lines of evidence that support the proposed changes are described in Table B-3 of Appendix B and should be cross reference to the Geological Mapping References presented within this Drawing.
This drawing provides a visual representation of the uncertainty associated with the proposed changes (i.e. red, amber, yellow and green).
The framework for assessing uncertainty in presented within Table B-2 of Appendix B.

LEGEND

- DCO BOUNDARY
- GEOLOGICAL BOUNDARY - NO CHANGE - BASED ON BGS MAPPING
- GEOLOGICAL BOUNDARY - GREEN LEVEL CONFIDENCE (HIGH)
- GEOLOGICAL BOUNDARY - YELLOW LEVEL (MODERATELY HIGH)
- GEOLOGICAL BOUNDARY - AMBER LEVEL CONFIDENCE (MODERATE)
- GEOLOGICAL BOUNDARY - RED LEVEL CONFIDENCE (LOW)
- FAULT - NO CHANGE - BASED ON BGS MAPPING
- FAULT - GREEN LEVEL CONFIDENCE (HIGH)
- FAULT - YELLOW LEVEL CONFIDENCE (MODERATELY HIGH)
- FAULT - AMBER LEVEL CONFIDENCE (MODERATE)
- FAULT - RED LEVEL CONFIDENCE (LOW)
- MASS MOVEMENT DEPOSITS
- CHELTENHAM SAND AND GRAVEL
- LIAS GROUP
- INFERIOR OOLITE GROUP
- FULLER'S EARTH FORMATION
- GREAT OOLITE GROUP FORMATION (LIMESTONE)
- GEOLOGICAL MAPPING REFERENCE (SEE APPENDIX B, TABLE B-3 FOR DETAILS)

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

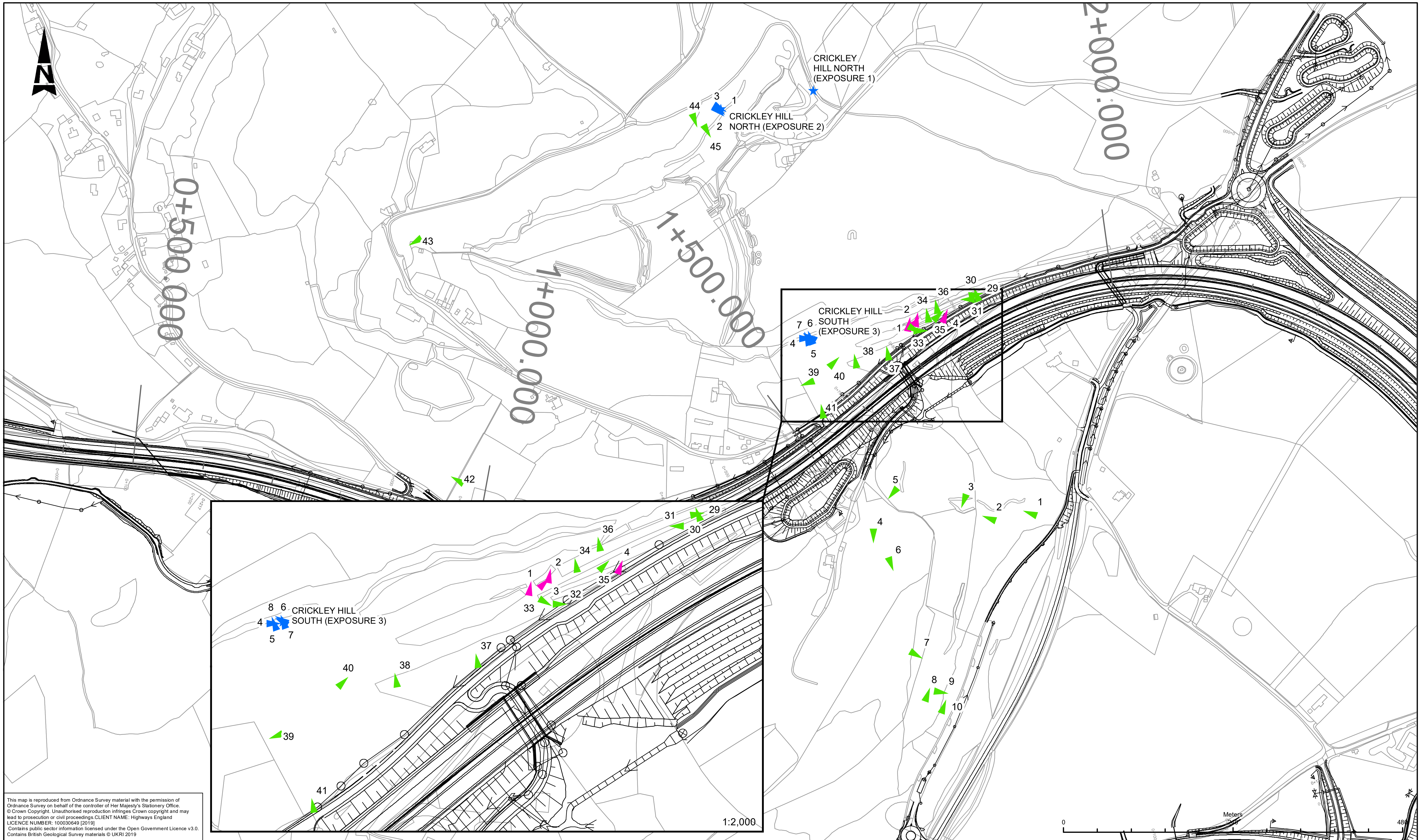
DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	28/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability	A3
Drawing Status	STAGE COMPLETED
Project Title	A417 MISSING LINK
Drawing Title	REINTERPRETED GEOLOGY MAP SHEET 2 OF 2
Scale	1:10,000
By	EB
Checked	LT
Approved	DR
Authorised	SW
Original Size	A3
Date (By)	28/04/21
Date (Checked)	28/04/21
Date (Approved)	28/04/21
Date (Authorised)	28/04/21
Drawing Number	HE551505 - ARP - HGT X_XX_XXXX_X - DR - LE - 000002
Revison	C01

ARUP

Client: highways england



LEGEND

SITE WALKOVER DATE

- 7 AND 8 AUGUST 2019
- 10 OCTOBER 2019
- 10 OCTOBER 2019 EXPOSURE LOCATIONS
- 7 NOVEMBER 2019

NOTE
REFER TO APPENDIX A FOR PHOTOGRAPHS AND FURTHER DETAILS OF OBSERVATIONS AT EACH LOCATION

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	23/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

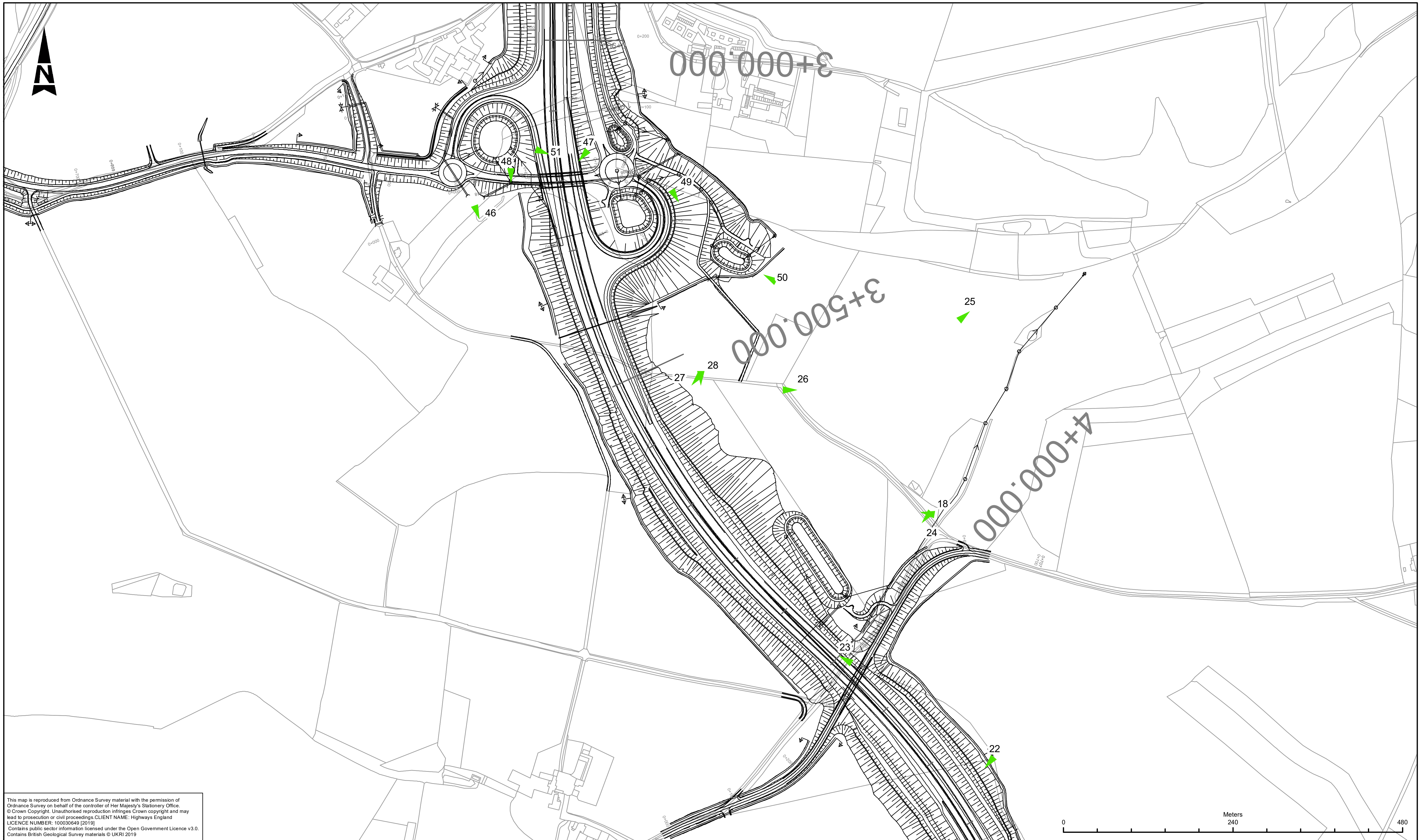
Project Title: A417 MISSING LINK

Drawing Title: GEOTECHNICAL SITE WALKOVER LOCATION PLAN SHEET 1 OF 3

Scale	By	Checked	Approved	Authorised
1:5,000	EB	LT	DR	SW
Original Size	**Date**	**Date**	**Date**	**Date**
A3	23/04/21	23/04/21	23/04/21	23/04/21

Drawing Number: HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X -DR- G -000017
Location | Type | Role | Number

Revision: C01



LEGEND

SITE WALKOVER DATE

- 7 AND 8 AUGUST 2019
- 10 OCTOBER 2019
- 10 OCTOBER 2019 EXPOSURE LOCATIONS
- 7 NOVEMBER 2019

NOTE
REFER TO APPENDIX A FOR PHOTOGRAPHS AND FURTHER DETAILS OF OBSERVATIONS AT EACH LOCATION

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	23/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

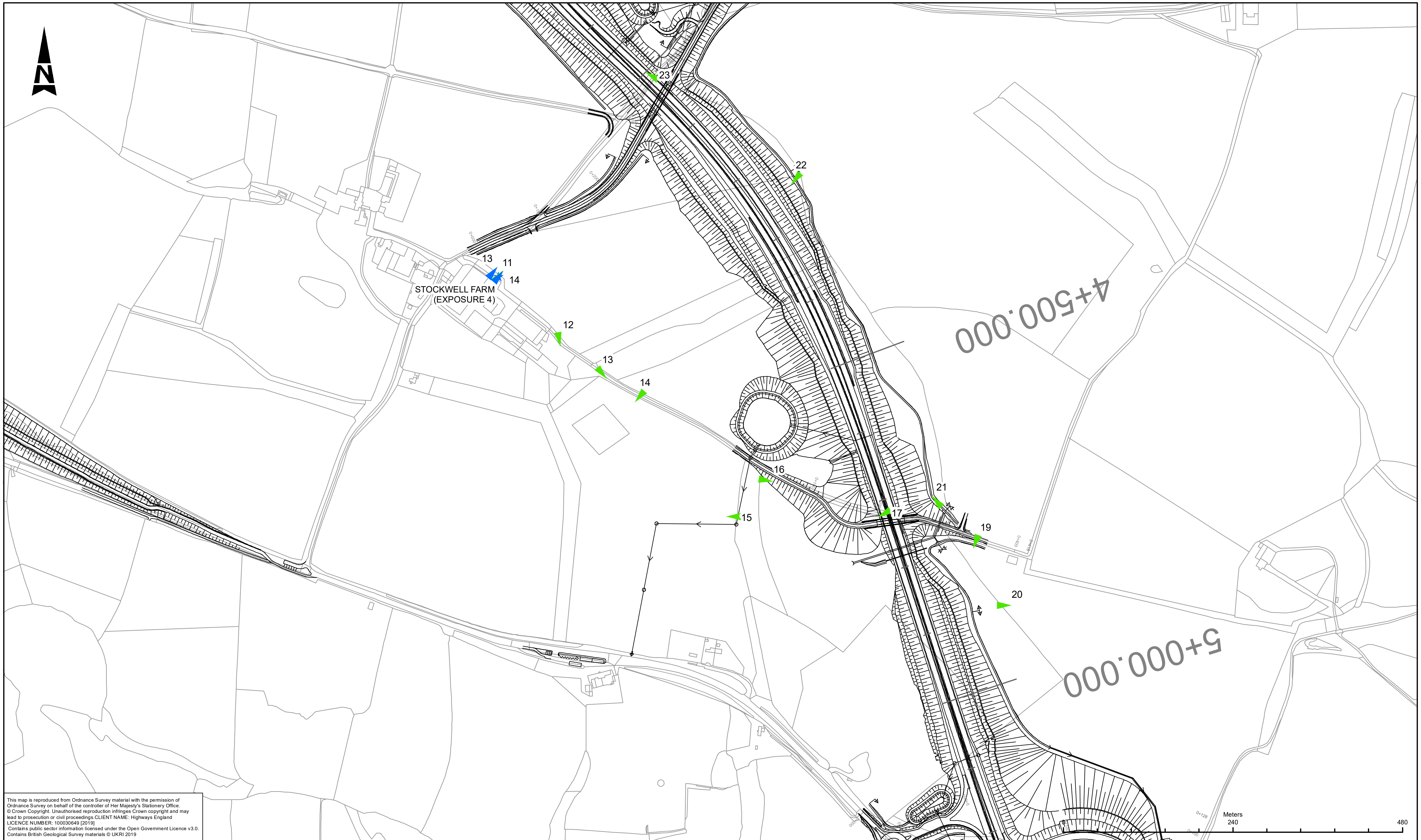
Project Title: A417 MISSING LINK

Drawing Title: GEOTECHNICAL SITE WALKOVER LOCATION PLAN SHEET 2 OF 3

Scale	By	Checked	Approved	Authorised
1:5,000	EB	LT	DR	SW
Original Size	Date	Date	Date	Date
A3	23/04/21	23/04/21	23/04/21	23/04/21

Drawing Number: HE PIN HE551506 - Originator ARP - Volume EGT
Location X_XX_XXXX_X - Type DR - Role G - Number 000018

Revision: C01



LEGEND

SITE WALKOVER DATE

- 7 AND 8 AUGUST 2019
- 10 OCTOBER 2019
- 10 OCTOBER 2019 EXPOSURE LOCATIONS
- 7 NOVEMBER 2019

NOTE
REFER TO APPENDIX A FOR PHOTOGRAPHS AND FURTHER DETAILS OF OBSERVATIONS AT EACH LOCATION

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	23/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: GEOTECHNICAL SITE WALKOVER LOCATION PLAN SHEET 3 OF 3

Scale	By	Checked	Approved	Authorised
1:5,000	EB	LT	DR	SW
Original Size	**Date**	**Date**	**Date**	**Date**
A3	23/04/21	23/04/21	23/04/21	23/04/21

Drawing Number: HE PIN | Originator | Volume
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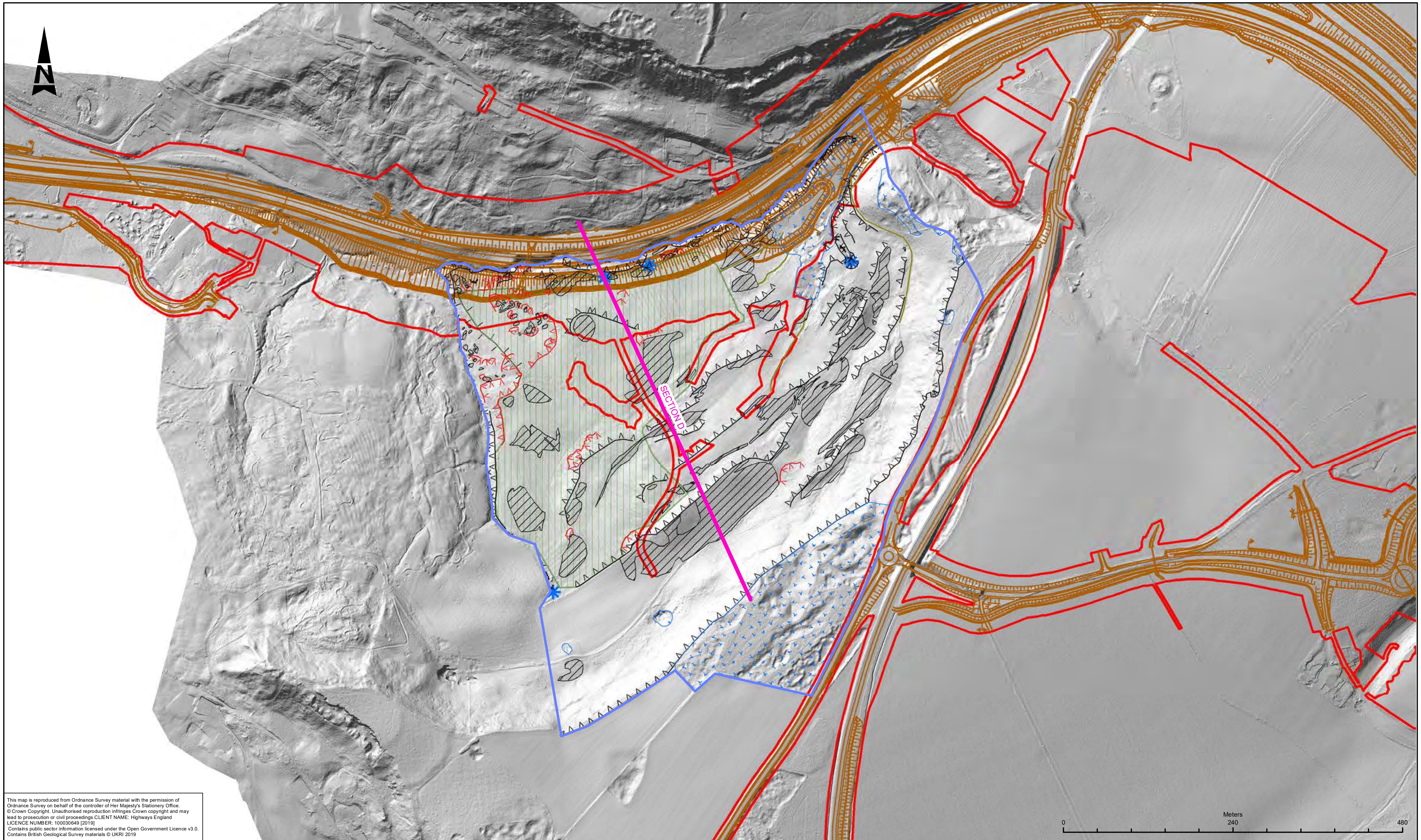
X_XX_XXXX_X - DR - G - 000019
Location | Type | Role | Number

Revison: C01



LEGEND

- COMBINED MODEL
- DCO BOUNDARY
- SLOPE ZONE 6
- SECTION LINES
- FLAT TERRAIN
- DISTURBED GROUND
- BASE OF SLOPE
- TOP OF SLOPE
- BACKSCARP
- LANDSLIDE TOE
- RIDGE
- GULLY
- SPRING
- TRACK
- RIDGE AND FURROWS

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	20/05/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability	Drawing Status
A3	STAGE COMPLETED

ARUP

Client: highways england

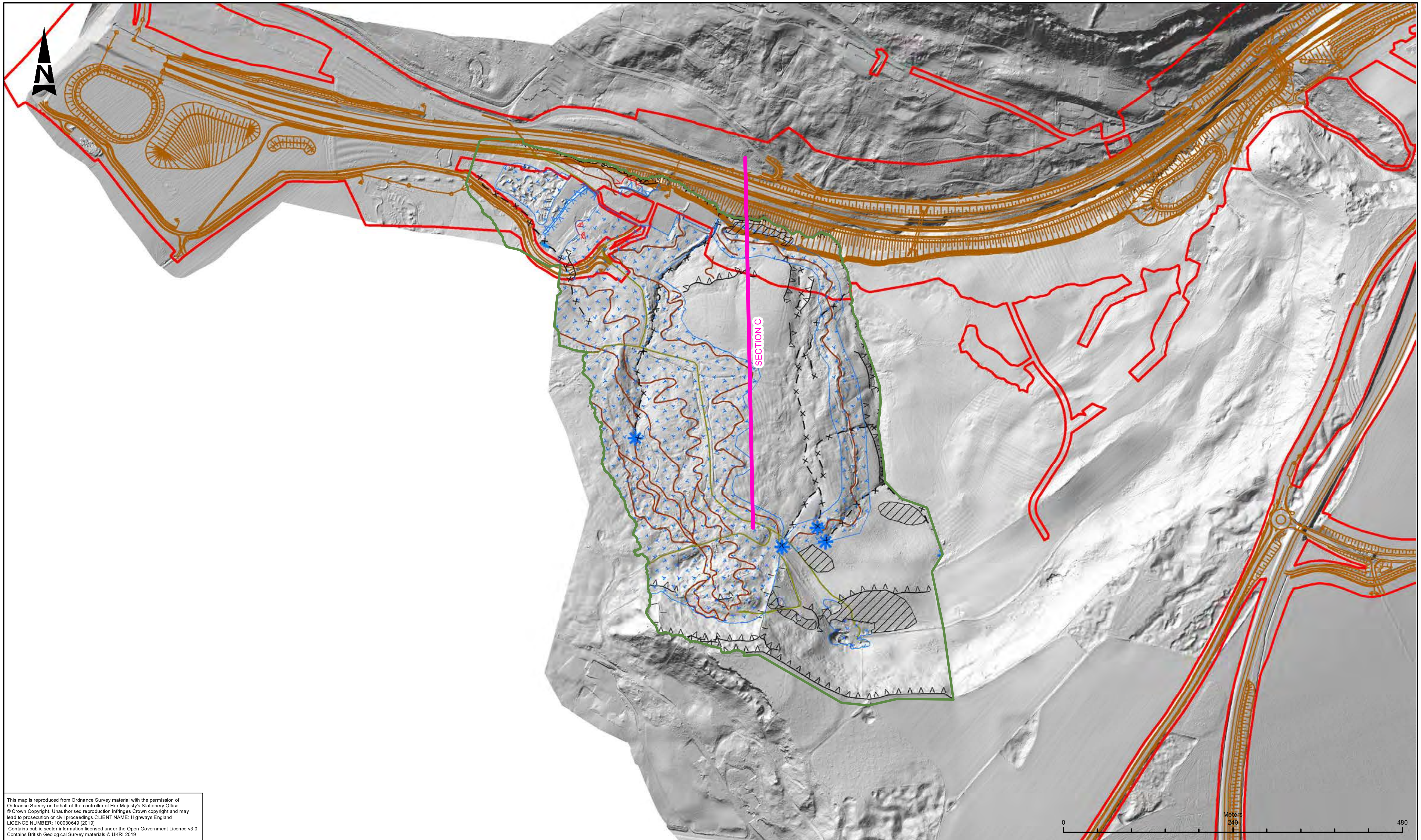
Project Title: A417 MISSING LINK

Drawing Title: SLOPE ZONE 6 GEOMORPHOLOGICAL MAP

Scale	By	Checked	Approved	Authorised
1:5,000	EB	LT	DR	SW
Original Size	Date	Date	Date	Date
A3	20/05/21	20/05/21	20/05/21	20/05/21

Drawing Number: HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X -DR- G -000001
Location | Type | Role | Number

Revison: C01



LEGEND

- COMBINED MODEL
- DCO BOUNDARY
- SLOPE ZONE 5
- SECTION LINES
- TOP OF ARTIFICIAL SLOPE
- BOTTOM OF ARTIFICIAL SLOPE
- FLAT TERRAIN
- DISTURBED GROUND
- TOP OF SLOPE
- LANDSLIDE TOE
- RIDGE
- GULLY
- SPRING
- TRACK
- POND
- BIKE TRACK

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

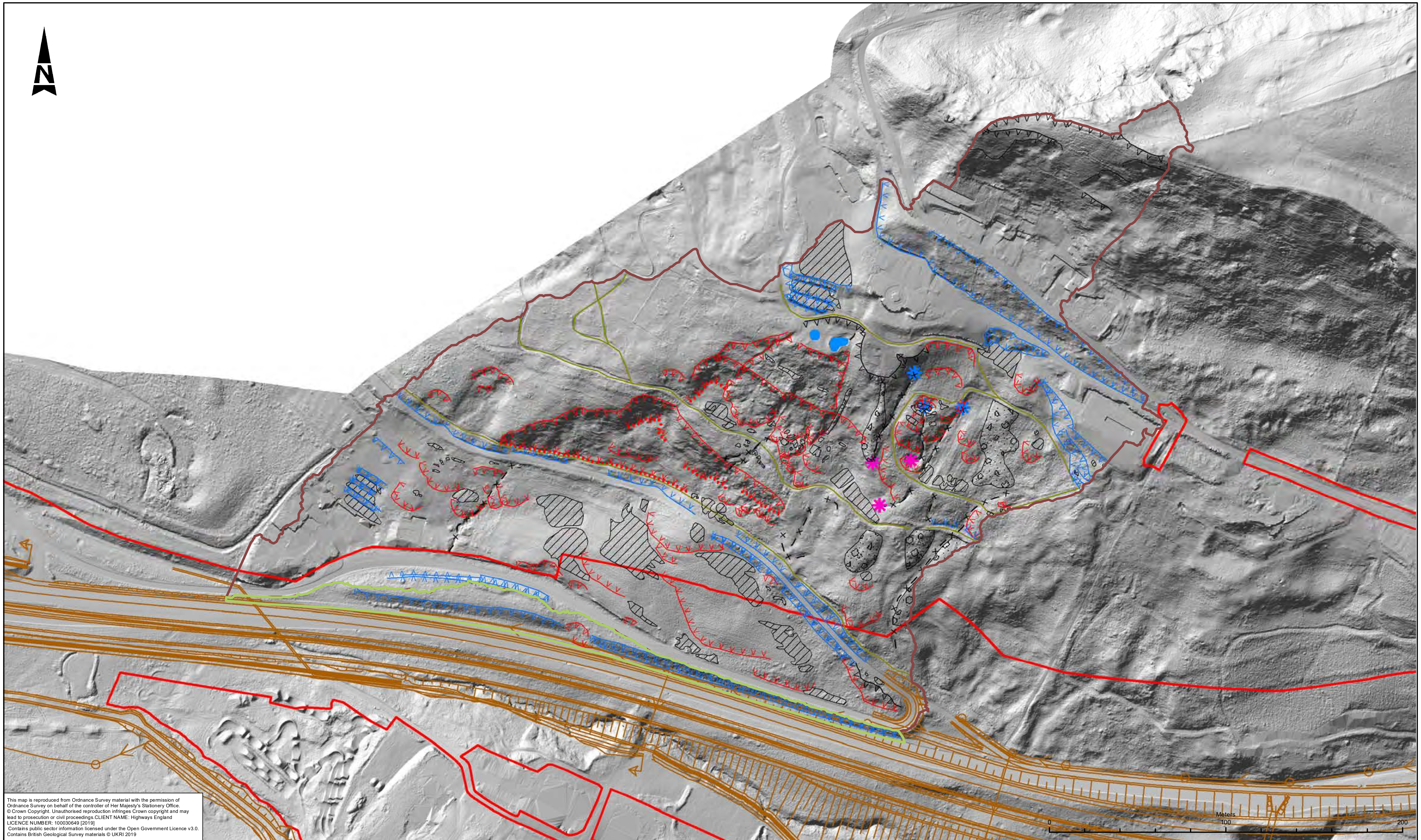
USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	20/05/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability	A3
Drawing Status	STAGE COMPLETED
Project Title	A417 MISSING LINK
Drawing Title	SLOPE ZONE 5 GEOMORPHOLOGICAL MAP
Scale	1:5,000
By	EB
Checked	LT
Approved	DR
Authorised	SW
Original Size	A3
Date	20/05/21
Date	20/05/21
Date	20/05/21
Date	20/05/21
Client	highways england
Drawing Number (HE PIN - Originator - Volume - Location - Type - Role - Number)	HE551506 - ARP - EGT X_XX_XXXX_X - DR - G - 000002
Revison	C01

ARUP



LEGEND

- COMBINED MODEL
- DCO BOUNDARY
- SLOPE ZONE 4
- SLOPE ZONE 4A
- TOP OF ARTIFICIAL SLOPE
- BOTTOM OF ARTIFICIAL SLOPE
- FLAT TERRAIN
- TOP OF SLOPE
- BACKSCARP
- BASE OF SCARP
- LANDSLIDE TOE
- GULLY
- CLIFF
- DEBRIS FLOW
- SPRING
- SINK
- TRACK
- POND

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	22/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

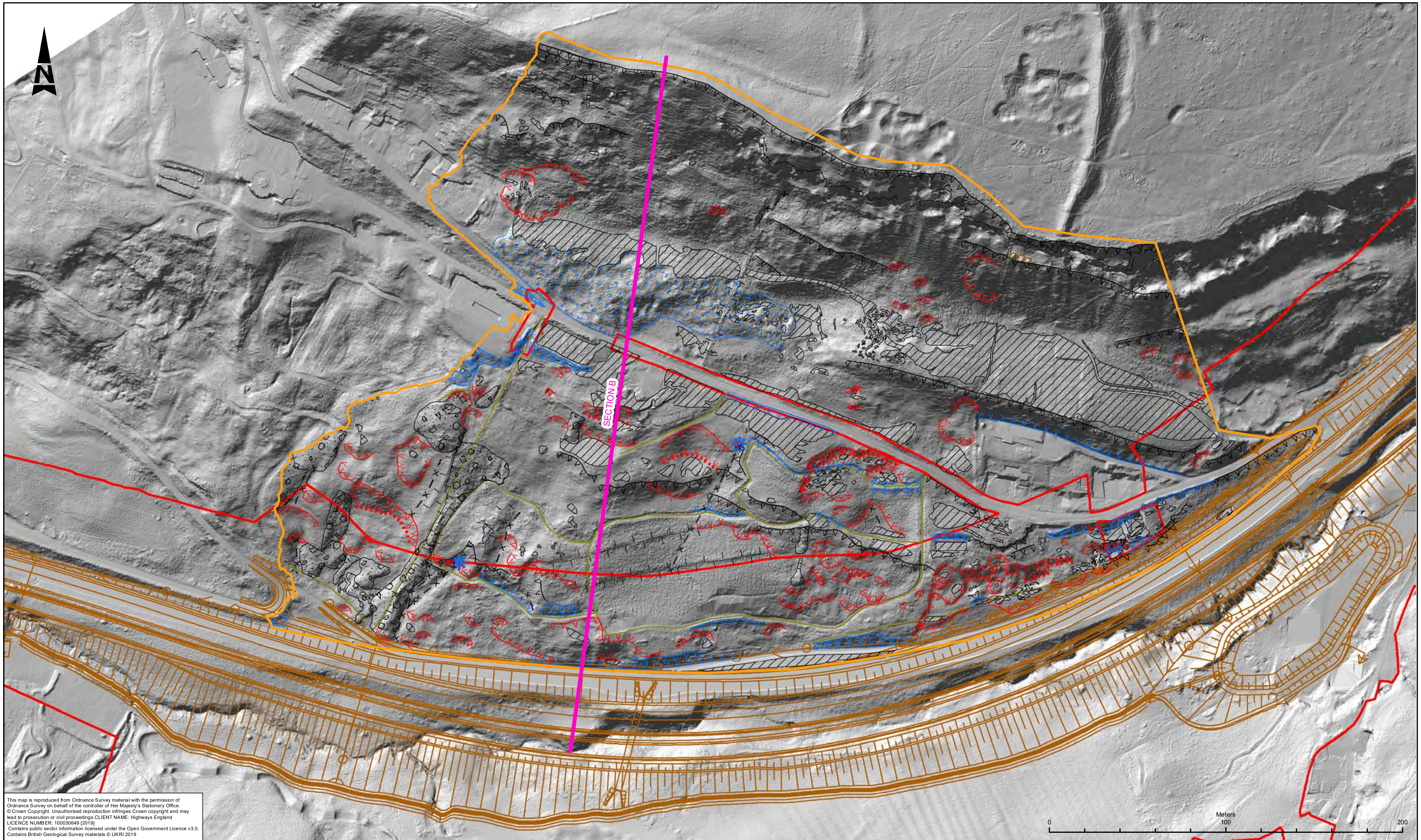
Suitability	A3
Drawing Status	STAGE COMPLETED
Project Title	A417 MISSING LINK
Drawing Title	SLOPE ZONE 4 AND 4A GEOMORPHOLOGICAL MAP
Client	highways england

ARUP

Scale	By	Checked	Approved	Authorised
1:2,000	EB	LT	DR	SW
Original Size	Date	Date	Date	Date
A3	22/04/21	22/04/21	22/04/21	22/04/21

Drawing Number
HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X - DR - G - 000003
Location | Type | Role | Number

Revison
C01



LEGEND

- COMBINED MODEL
- DCO BOUNDARY
- SLOPE ZONE 3
- SECTION LINES
- TOP OF ARTIFICIAL SLOPE
- BOTTOM OF ARTIFICIAL SLOPE
- FLAT TERRAIN
- DISTURBED GROUND
- TOP OF SLOPE
- BACKSCARP
- BASE OF SCARP
- LANDSLIDE TOE
- MOUND
- RIDGE
- GULLY
- CLIFF
- DEBRIS FLOW
- SPRING
- TRACK

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	22/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability	Drawing Status
A3	STAGE COMPLETED

ARUP

Client
highways england

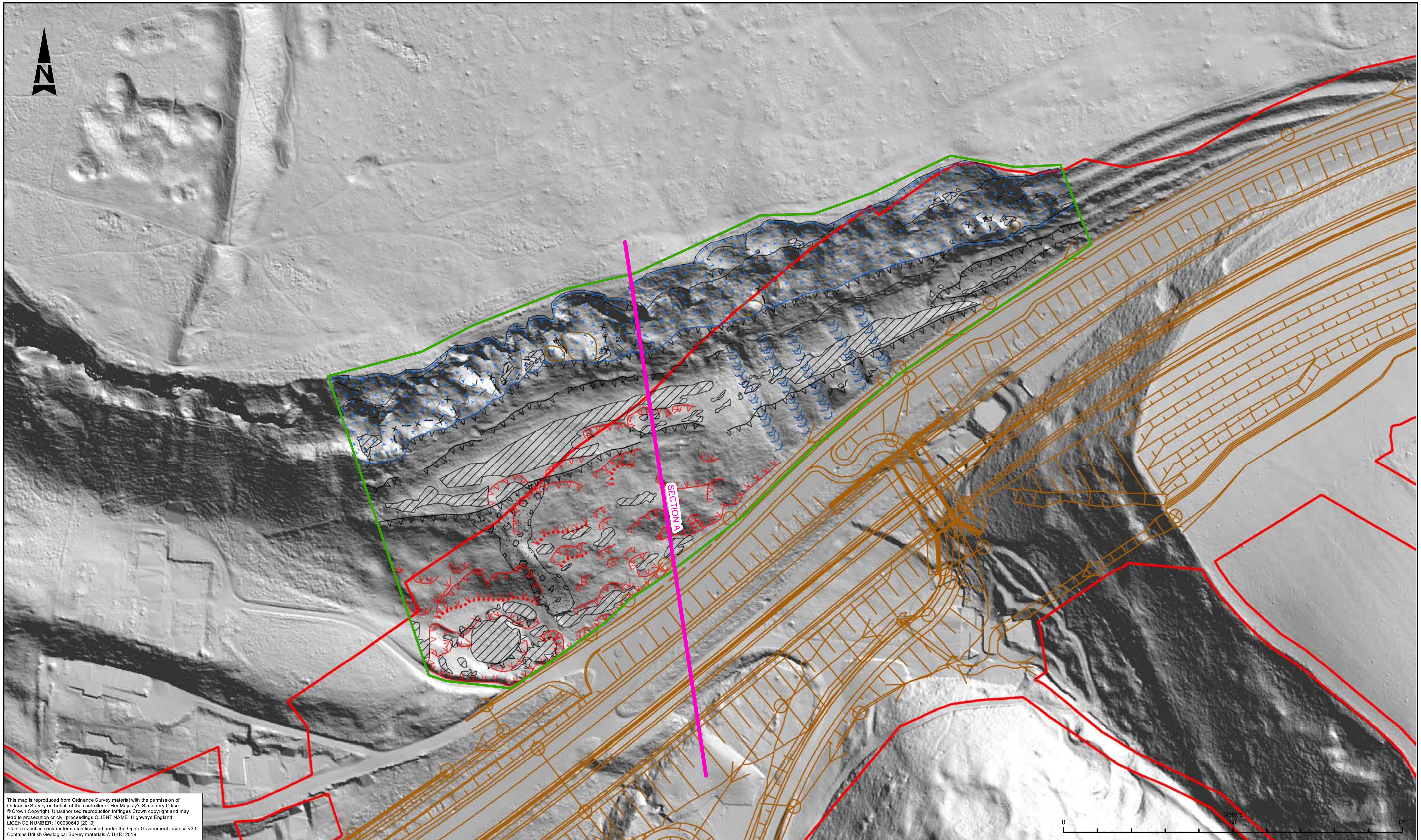
Project Title
A417 MISSING LINK

Drawing Title
SLOPE ZONE 3
GEOMORPHOLOGICAL MAP

Scale	By	Checked	Approved	Authorised
1:2,000	EB	LT	DR	SW
Original Size	Date	Date	Date	Date
A3	22/04/21	22/04/21	22/04/21	22/04/21

Drawing Number
HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X - DR - G - 000004
Location | Type | Role | Number

Revison
C01



LEGEND

- SLOPE ZONE 2
- COMBINED MODEL
- DCO BOUNDARY
- SECTION LINES
- TOP OF ARTIFICIAL SLOPE
- FLAT TERRAIN
- DISTURBED GROUND
- TOP OF SLOPE
- BACKSCARP
- BASE OF SCARP
- LANDSLIDE TOE
- TRENCH DRAIN
- MOUND
- RIDGE
- GULLY
- CLIFF
- DEBRIS FLOW

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	22/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

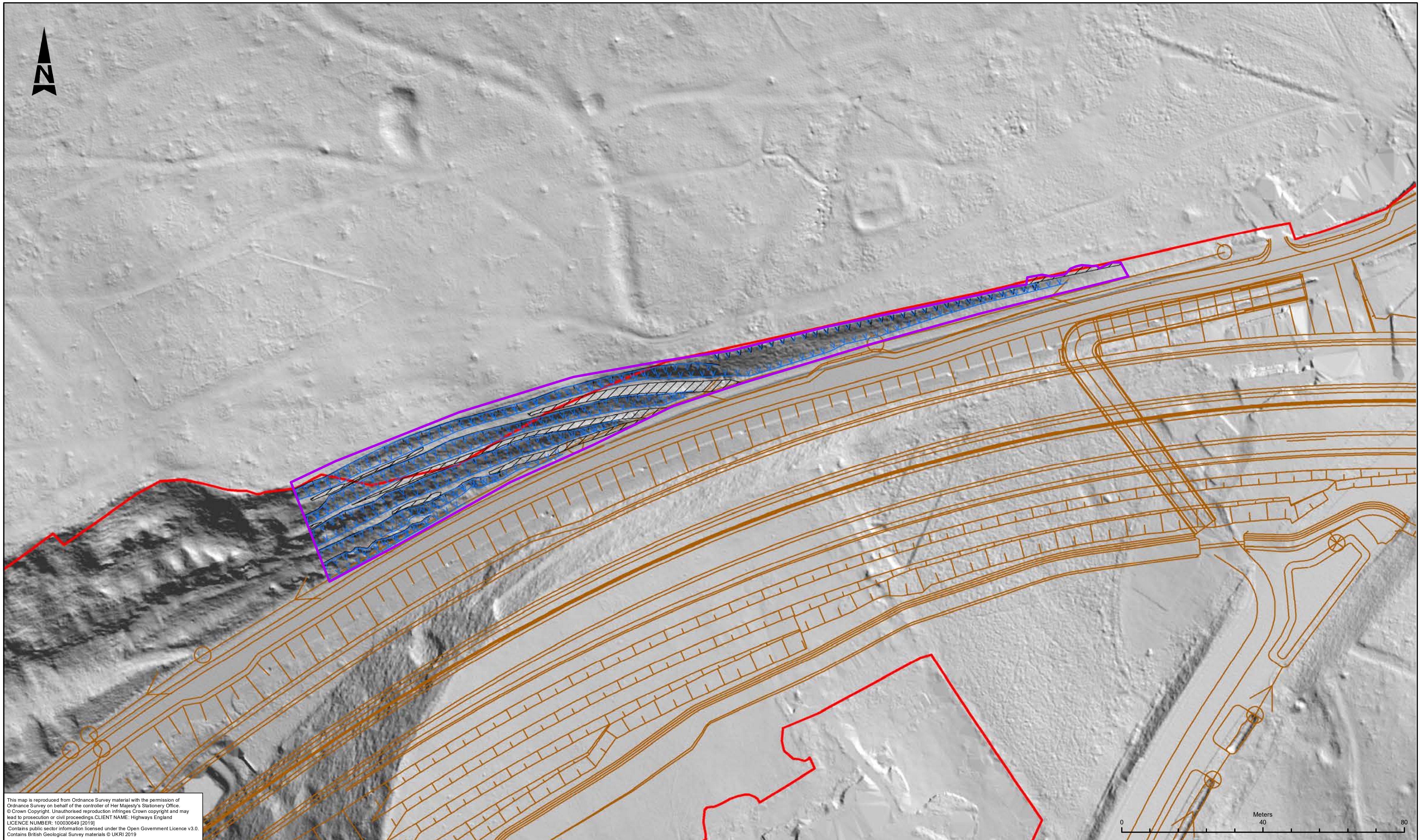
Project Title: A417 MISSING LINK

Drawing Title: SLOPE ZONE 2 GEOMORPHOLOGICAL MAP

Scale	By	Checked	Approved	Authorised
1:1,250	EB	LT	DR	SW
Original Size	Date	Date	Date	Date
A3	22/04/21	22/04/21	22/04/21	22/04/21

Drawing Number
HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X - DR - G - 000005
Location | Type | Role | Number

Revison: C01



LEGEND

- COMBINED MODEL
- DCO BOUNDARY
- SLOPE ZONE 1
- TOP OF ARTIFICIAL SLOPE
- BOTTOM OF ARTIFICIAL SLOPE
- FLAT TERRAIN
- TOP OF SLOPE
- CLIFF

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

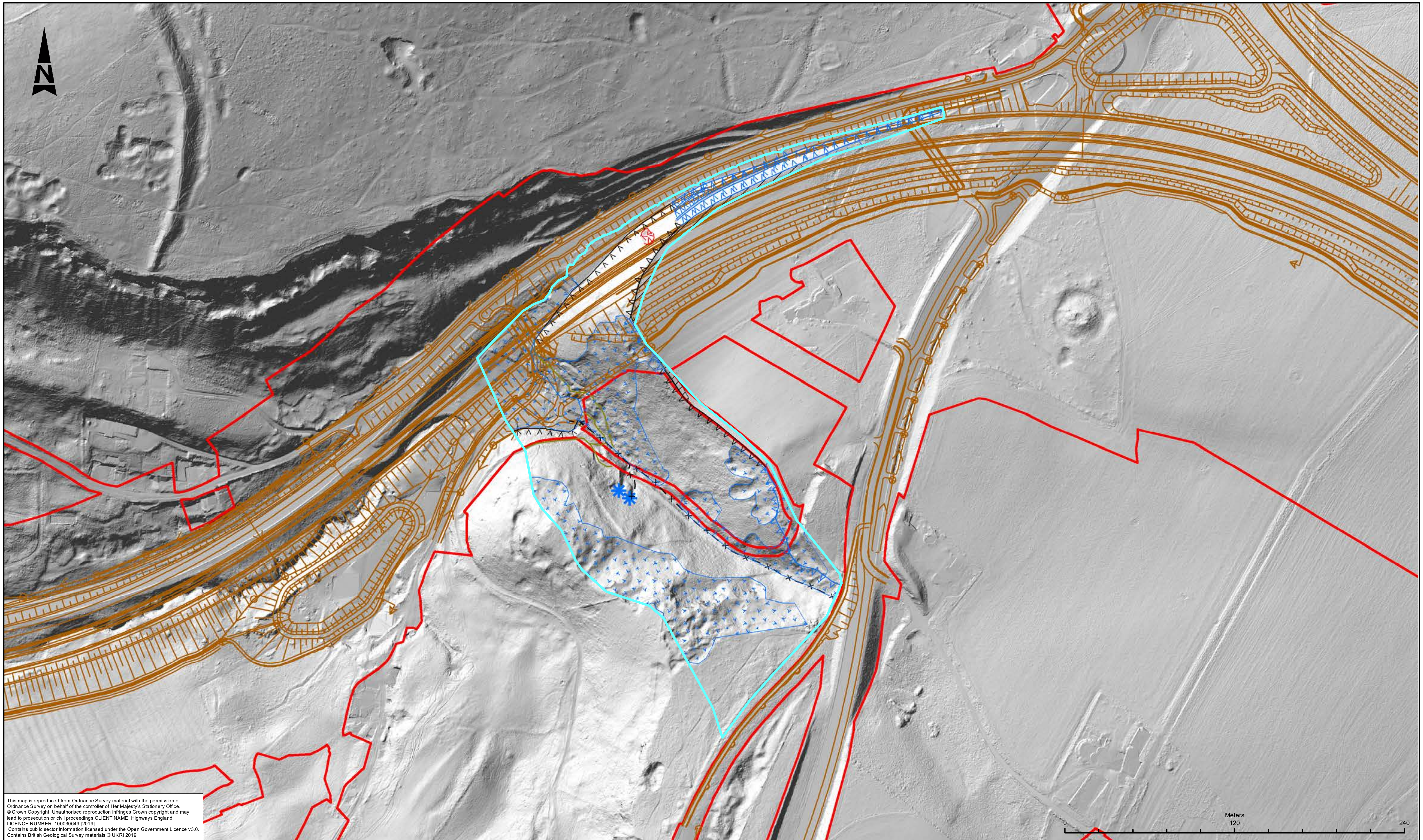
Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	22/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability	A3
Drawing Status	STAGE COMPLETED
Client	highways england
Project Title	A417 MISSING LINK
Drawing Title	SLOPE ZONE 1 GEOMORPHOLOGICAL MAP

Scale	By	Checked	Approved	Authorised
1:1,000	EB	LT	DR	SW
Original Size	Date	Date	Date	Date
A3	22/04/21	22/04/21	22/04/21	22/04/21

Drawing Number: HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X - DR - G - 000014
Location | Type | Role | Number

Revison: C01



LEGEND

- COMBINED MODEL
- DCO BOUNDARY
- SLOPE ZONE 7
- TOP OF ARTIFICIAL SLOPE
- BOTTOM OF ARTIFICIAL SLOPE
- FLAT TERRAIN
- DISTURBED GROUND
- BASE OF SLOPE
- TOP OF SLOPE
- BACKSCARP
- LANDSLIDE TOE
- GULLY
- SPRING
- TRACK

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	22/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability: A3
Drawing Status: STAGE COMPLETED

ARUP

Client: highways england

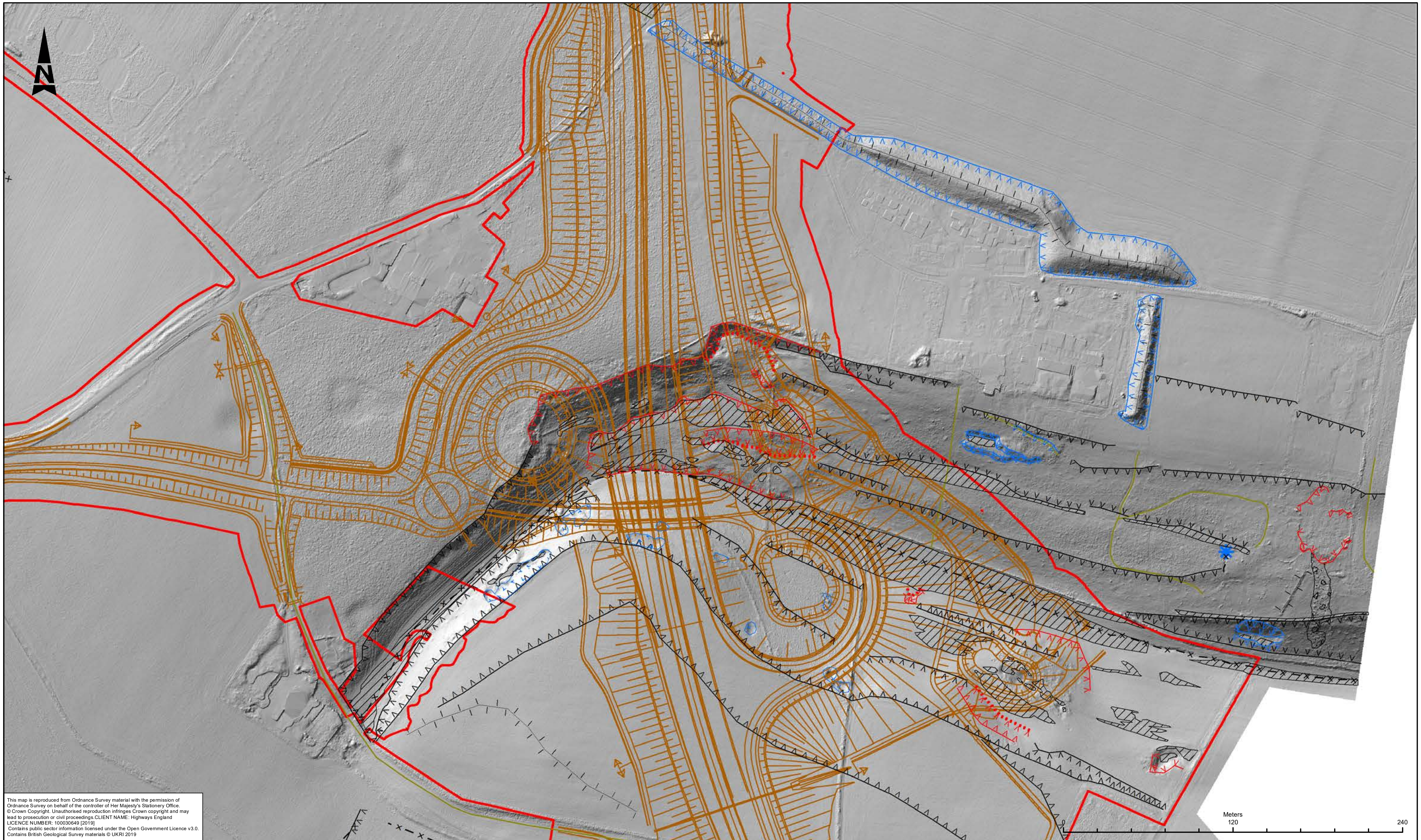
Project Title: A417 MISSING LINK

Drawing Title: SLOPE ZONE 7 GEOMORPHOLOGICAL MAP

Scale	By	Checked	Approved	Authorised
1:2,500	EB	LT	DR	SW
Original Size	**Date**	**Date**	**Date**	**Date**
A3	22/04/21	22/04/21	22/04/21	22/04/21

Drawing Number: HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X -DR- G -000015
Location | Type | Role | Number

Revison: C01



LEGEND

- COMBINED MODEL
- TOP OF ARTIFICIAL SLOPE
- BOTTOM OF ARTIFICIAL SLOPE
- FLAT TERRAIN
- DISTURBED GROUND
- TOP OF SLOPE
- BASE OF SLOPE
- BACKSCARP
- BASE OF SCARP
- LANDSLIDE TOE
- RIDGE
- GULLY
- DEBRIS FLOW
- SPRING
- TRACK
- DCO BOUNDARY

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
C01	28/04/21	APPLICATION SUBMISSION (MAY 2021)	EB	LT	DR	SW

Suitability	Drawing Status
A3	STAGE COMPLETED

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title: SHAB HILL GEOMORPHOLOGICAL MAP

Scale	By	Checked	Approved	Authorised
1:2,500	EB	LT	DR	SW
Original Size	Date	Date	Date	Date
A3	28/04/21	28/04/21	28/04/21	28/04/21

Drawing Number
HE PIN | Originator | Volume
HE551506 - ARP - EGT
X_XX_XXXX_X - DR - G - 000016
Location | Type | Role | Number

Revison: C01