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C861

Summary assessment of ground conditions for Whitmore Heath Tunnel

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1 Summary

1.1.1 This report presents both desk based assessment and early results from the recent ground investigation in the Whitmore Heath area where tunnelling Works are proposed.

1.1.2 To date seven boreholes have been completed at locations across Whitmore Heath to progress the preliminary design of the Whitmore Heath tunnel. In-situ strength testing, downhole geophysics, permeability testing and groundwater level monitoring have been undertaken. Samples recovered from the ground have been sent to a laboratory for testing and this is currently underway.

1.1.3 As anticipated, the solid geology encountered at Whitmore Heath comprises the Wilmslow Sandstone Formation and the Chester Formation (with Pebble Beds). Some superficial deposits were also encountered, but these are limited in their vertical and lateral extent. Typically, the ground profile was found to comprise a weathered bedrock zone (soil) overlying extremely weak to weak rock[1]. These findings are within the range anticipated and do not change the basis of the preliminary design assumptions with respect to tunneling.

1.1.4 Groundwater levels measured thus far are below the proposed tunnel level. Requirements for dewatering during tunnel installation is therefore unlikely.

1.1.5 This initial assessment of the findings from the ground investigation at Whitmore Heath indicates no reason to alter the assumptions on ground and groundwater conditions based on the original desk study assessment which informed the initial preliminary design.

2 Introduction

2.1.1 The Proposed Scheme at Whitmore Heath includes two bored tunnels with two porous portals at either end. It passes through the side of the hill below Whitmore Heath (as shown in the plan in Figure 1) and comprises:

- 690m long 8.8m inside diameter twin bored tunnels (Chainage 232+217 to Chainage 232+907);
- 238m long cut and cover tunnel towards south (separated twin tunnels for up and down line individually, Chainage 231+979 to Chainage 232+217);
- 150m long porous portals at both ends of the tunnel (Chainage 231+829 to Chainage

[1] Extremely weak to weak rock classifications are engineering terms used in British Standard, BS 5930:2015, to define rocks that have unconfined compressive strengths of between 0.6MPa and 25MPa.

231+979 and Chainage 232+907 to 233+057). The south porous portal connects to the cut and cover tunnel. The north porous portal connects to the bored tunnel;

2.1.2 This report provides a preliminary assessment of the ground conditions at Whitmore Heath supported by desk based assessment as well as the early findings from the ongoing ground investigation in the area. The recent ground investigation was designed to assess ground and ground water conditions to:

- confirm previous assumptions on ground conditions made for the initial preliminary design phase considered in the deposited scheme.
- confirm the ground and groundwater conditions that inform the preliminary design stage of the tunnels in the Whitmore Heath area;

2.1.3 A summary of both desk based assessment of anticipated ground conditions and early ground condition interpretation from the seven boreholes completed between 19th April and 8th June 2018 at Whitmore Heath is presented in this report.

2.1.4 In addition, this report considers, an early assessment of the geotechnical properties of the ground and engineering implications in relation to the proposed twin bore tunnel.

2.2 Limitation of this report

2.2.1 The full geotechnical engineering assessment of the ground conditions will be possible once site investigation fieldwork, geophysical data acquisition and processing, water level monitoring and laboratory testing have been completed. As such, the recommendations and conclusions provided in this report may be subject to amendment.

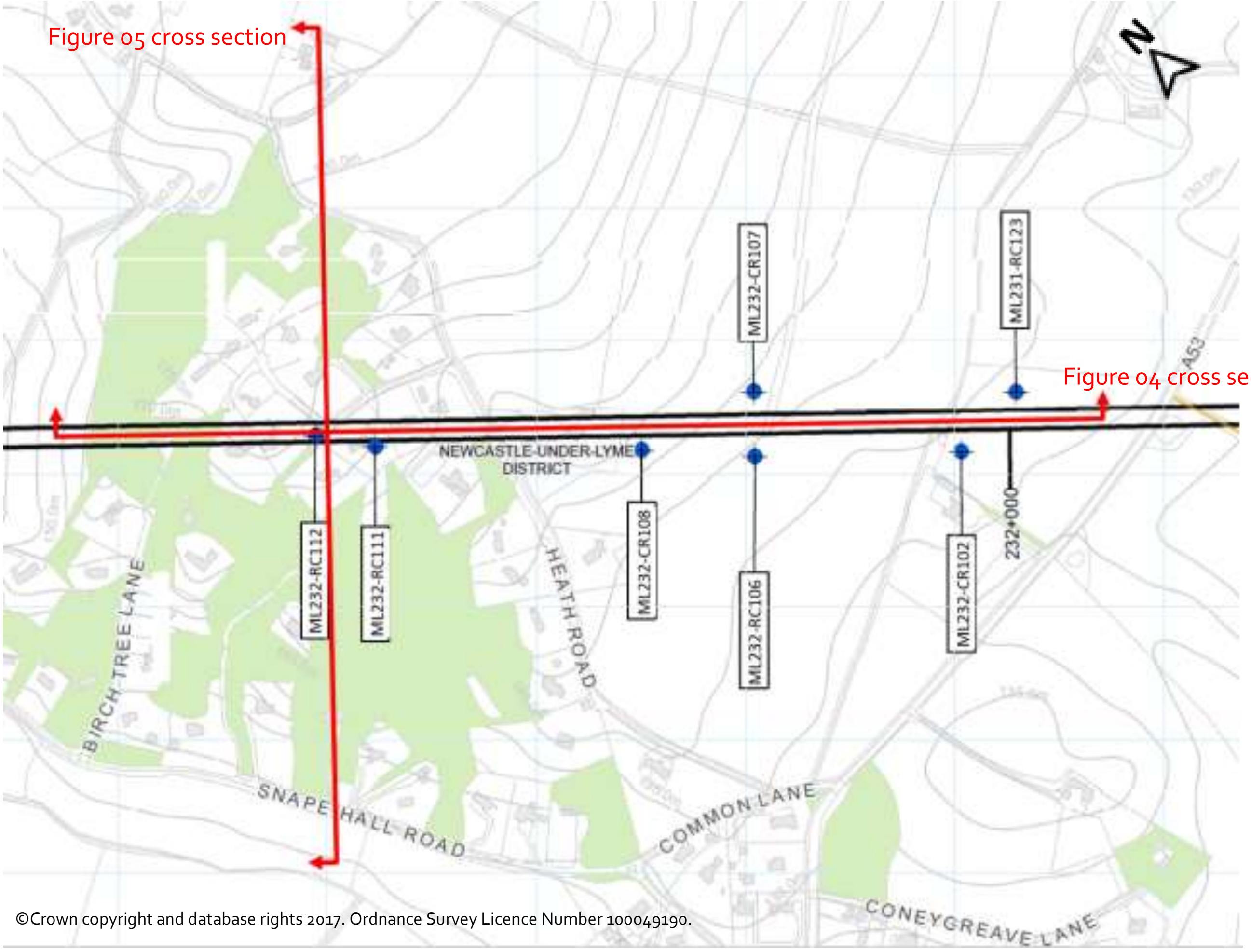

Figure 1 Borehole Location Plan and location of cross sections

3 Desk based assessment

3.1 Topography

3.1.1 The topography along the proposed route at Whitmore Heath (Chainage 232+000 to 232+850), forms a ridge composed of the Chester Formation of the Sherwood Sandstone Group. Local elevations rise from 135 m above Ordnance Datum (mOD) in the south to a peak of 175 mOD (Chainage 232+700), before reducing back down to 140 mOD (Chainage 232+900).

3.2 Historical Land Use

3.2.1 Historical plans (1:2500 and 1:10000) have been reviewed for Whitmore Heath with respect to former land uses that could potentially impact on the Proposed Scheme design.

3.2.2 There is evidence on published historical mapping of numerous pits for extracting marl or sand and gravel over a number of years which is summarised in in Figure 2 below. It does appear that these quarries were open cast rather than mined. Due to the nature of the Sherwood Sandstone the presence of mapped 'sand and gravel' quarries/pits rather than 'rock' quarries in the area links to the anticipated weak and friable nature of the rock when excavated (covered later in this report), particularly over shallow weathered sections of bedrock close to the surface.

3.2.3 It is not clear, from mapping, if these quarries were backfilled as part of the residential development of the Whitmore Heath area, or if properties were constructed on quarry spoil deposited around the area.

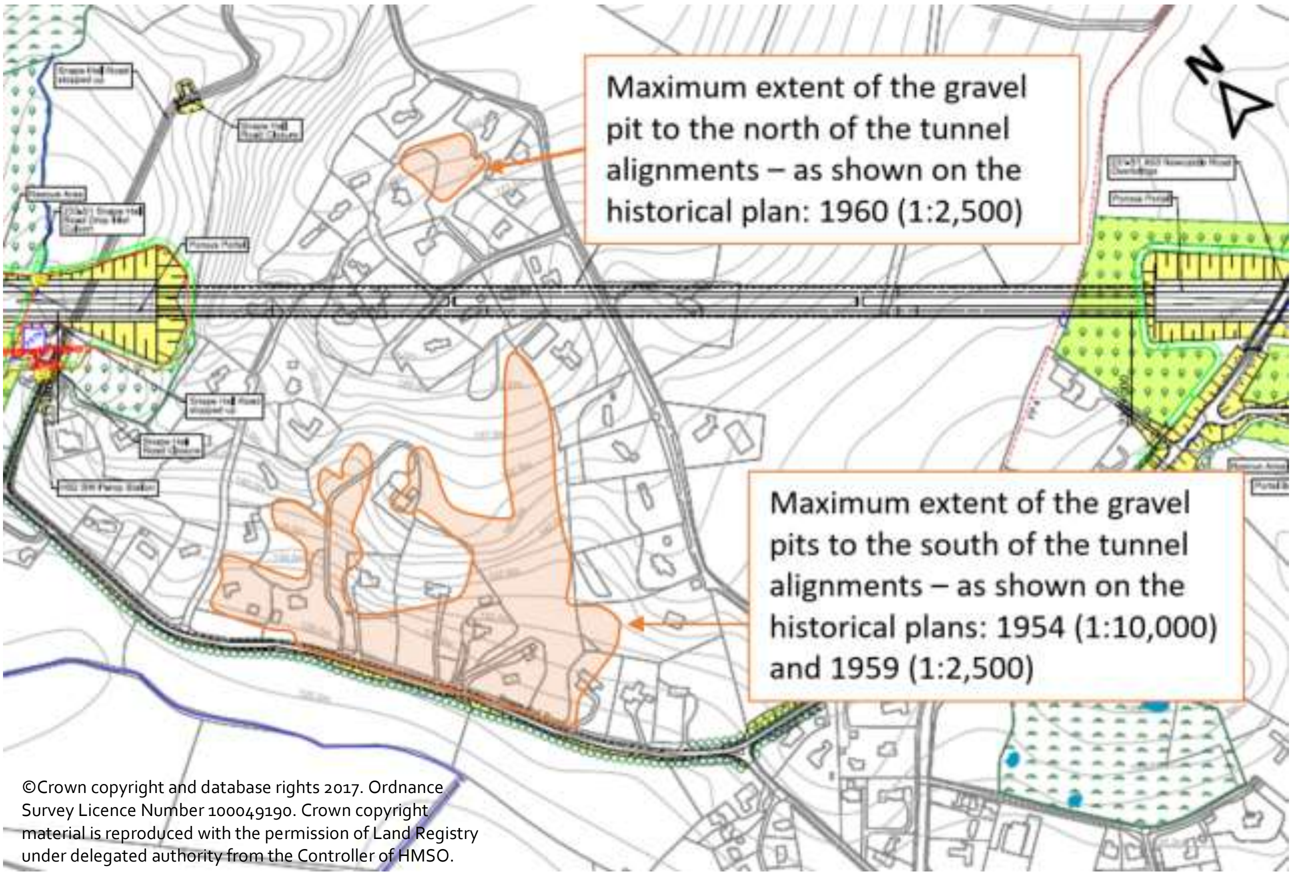

Figure 2 Approximate extent of Gravel Extraction activity at Whitmore Heath based on Ordnance Survey Maps

3.3 Geology and Groundwater Conditions

Geological Mapping

3.3.1 The British Geological Survey (BGS) geological mapping sheets, 1: 10,000 Series form the basis for identifying the solid geology underlying the Whitmore Heath area. The area is covered by several map sheets. An extract from the available BGS geological mapping for the Whitmore Heath area including a key is shown in Figure 3.

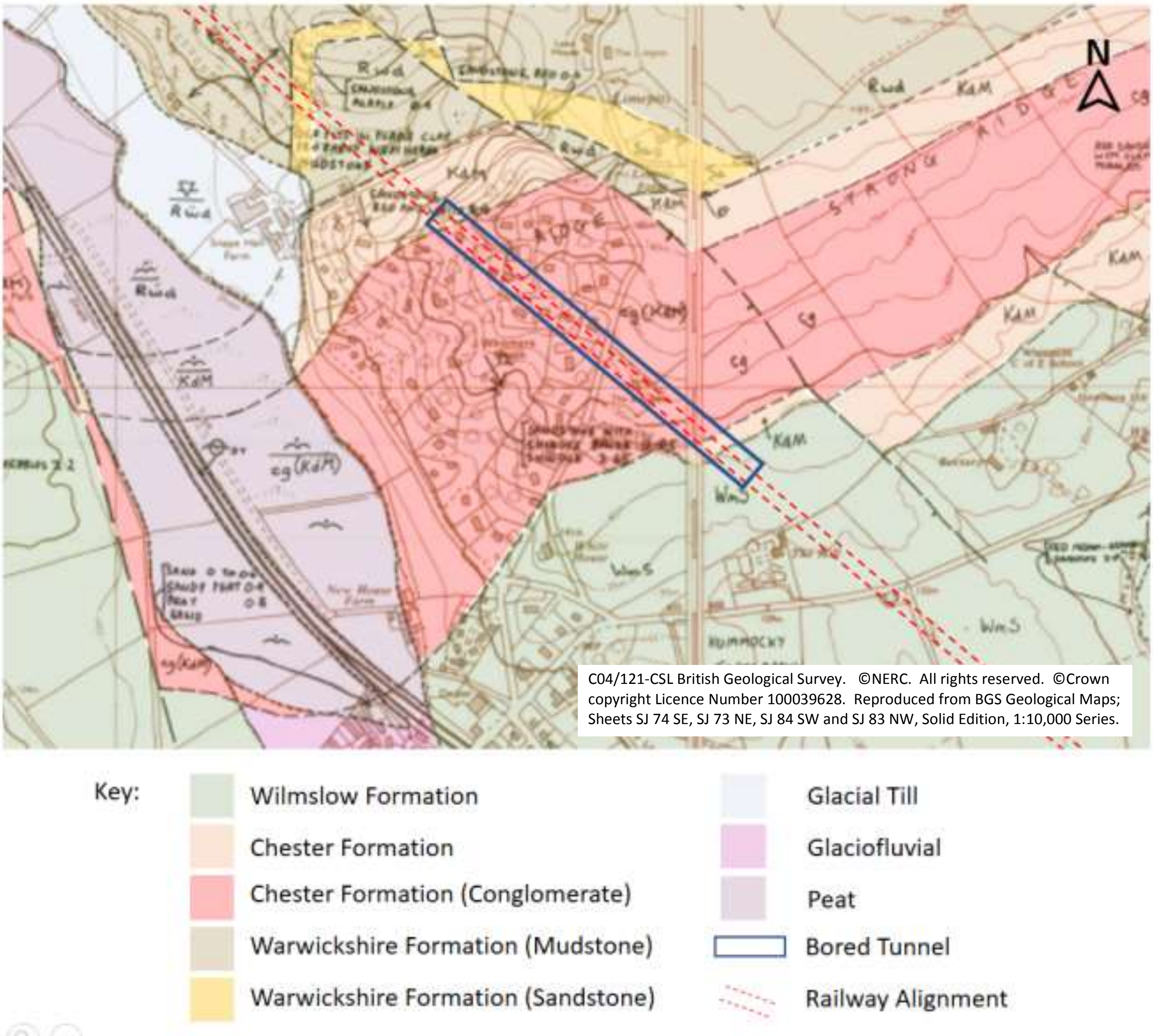

Figure 3 Combined extracts taken from the BGS Geological Map 1:10,000 series (based on Sheets; SJ 74 SE, SJ 73 NE, SJ 84 SW and SJ 83 NW) for the Whitmore Heath area.

Superficial Geology

3.3.2 Published information indicates limited occurrence of 'superficial' deposits across the Whitmore Heath location. Where present natural deposits will likely only be 2 – 3 m thick.

3.3.3 As discussed previously the historical development of the site may have resulted in some 'made ground' associated with open cast quarrying and or backfilling of open cast mines may be present across the site. Depths cannot be estimated from desk study assessment. These materials appear to be off the line of the proposed tunnels.

Solid Geology

3.3.4 Due to a lack of mapped superficial deposits at Whitmore Heath, the solid geology is anticipated to be encountered at shallow depth (below the topsoil). At Whitmore Heath the BGS maps identify that the Wilmslow and Chester Formations of the Sherwood Sandstone Group underlay the site as shown in Figure 2 above.

3.3.5 These two formations are described as alternating bands of Sandstone, Mudstone and some Conglomeratic Formations that dip to the south east. The Wilmslow Formation lies above the Chester Formation and due to the structural dip of the beds is only present at the southern end of the tunnel where it outcrops at the surface (from approximately Ch 231+825 to Ch 232+500). The Wilmslow Formation becomes thinner heading northwards along the route. The Wilmslow Formation typically contains fewer pebbly sandstones and conglomerates than the Chester Formation.

3.3.6 The British Geological Survey Memoir, Geology of the country around Stoke-on-Trent, notes that the boundary between the Wilmslow and the Chester Formation is often poorly defined and is often taken to be when at least a 20m thick sandstone layer, with rare pebbles occurrence, is observed overlying the pebbly sandstones of the Chester 'Pebble' Beds.

3.3.7 The Chester Formation is likely to be 50 – 60 m thick. It comprises a conglomerate outcropping at the ground surface over the majority of the Whitmore Heath area.

3.3.8 Underlying the Chester Formation is the Warwickshire Group, predominantly Mudstone but may also feature some substantial sandstone bands. It is shown to outcrop within the northern end of the Whitmore Heath area but outside the section in tunnel.

3.3.9 The Wilmslow and Chester Formations have been affected by progressive weathering, the depth and degree of weathering of the rock will therefore vary along the route. Generally, the upper 5m to 10m of material is weathered to a residual soil i.e. to a sand and gravel consistency.

3.3.10 The Sherwood Sandstone Group is generally documented in published papers to have a lack of discontinuities or fractures in situ although occasional discontinuities could be anticipated.

3.3.11 A northwest to southeast trending fault is shown on the geological maps at approximately 200 m to the east of the tunnel alignment. The fault is downthrown to the southwest. Further faulting is present in the surrounding area due to past regional tectonic activity.

Published Data on the Sherwood Sandstone Group

3.3.12 The Sherwood Sandstone Group is present across much of the UK and has been encountered during numerous site investigations and civil engineering works leading to a good understanding of its engineering properties. It is widely reported in published papers (eg Buist and Thompson) that obtaining representative samples using traditional site investigation drilling is extremely difficult due to the weak cementation holding the material together. This results in the rock breaking down as a result of the drilling process making sample recovery at times providing poor and/or unrepresentative of the in situ rock mass.

Previous Ground Investigation data in the Public Domain

3.3.13 A historic borehole record, drilled at the nearby to Whitmore Heath (reference location 'The Rectory') has been obtained from the BGS database. The date of the borehole is unclear but does not meet current logging standards. The log has been reviewed and although it is lacking in detail it reports the presence of Sandstones and Conglomerates from shallow depth, suggesting the borehole was logged as encountering a rock deposit rather than soil even though the recovery was reported as sand and gravel. The borehole was drilled using a rock roller drill bit with air flush which recovers completely disturbed samples (drill cuttings only).

3.3.14 Published ground investigation data for the Sherwood Sandstone Group reports Unconfined Compressive Strengths from laboratory testing of suitably recovered rock samples to be in the range of 0.5 to 5 MPa (Yates 1992). This equates to a rock described as having very weak and weak rock strength, which is consistent with Arup's own project experience.

Hydrogeological setting

3.3.15 Several springs are present in the area associated with the Sherwood Sandstone.

3.3.16 The Sherwood Sandstone is at the surface for much of this section, and forms part of a regional aquifer that is abstracted for water supply. There are several important abstraction *Sites* (pumping stations) and a scatter of Environment Agency (EA) observation boreholes. These observation boreholes record mean groundwater levels at elevations between 99.0 m OD and 108 m OD. The groundwater is therefore anticipated at a depth of 20 – 70 m below surface level at Whitmore Heath.

3.3.17 It is noted that the indicated groundwater elevation (108 m OD) closely corresponds with the base of a nearby valley (Meece Valley), suggesting that the elevation of the groundwater within the Sherwood Sandstone is locally controlled by the topography.

3.4 Considerations for Initial Preliminary Tunnel Design

3.4.1 The initial preliminary design for the Whitmore Heath Tunnel, includes 690 m long twin bored tunnels with a 238 m long cut and cover tunnel. However, uncertainty regarding the ground conditions means that the method of tunnelling has yet to be finalised.

3.4.2 The following assumptions were made in the tunnel assessment with respect to ground conditions based on topography and the desk based assessment of site history and geological setting:-

- The geology was assumed to be rock. The use of a tunnel boring machine (TBM) was considered most applicable for tunnel excavation. However, due to uncertainty about ground conditions, mined tunnelling was also considered.
- Potential ground settlement assessment above the tunnel below Whitmore Heath were based on conservative assumptions of tunnelling method i.e. a mined tunnel and no dewatering requirements.

4 Current Preliminary Ground Investigation

4.1 Outline of investigation to date

4.1.1 Ground Investigation has been underway at Whitmore Heath since April 2018 and seven boreholes have been completed and logged to date. The depths of these boreholes range from 43 m to 85 m. The approximate positions are shown on the borehole location plan is shown in Figure 1 and includes the borehole references.

4.1.2 The preliminary ground investigation has been designed to provide good quality information regarding ground conditions at intervals along the proposed tunnel route. The investigation has comprised rotary core drilling, drilling parameter measurement, in-situ testing and geophysical logging of the borehole walls. The information gained is not intended to meet detailed design requirements but should be sufficient to allow preliminary design options to be developed and to support the choice of tunnelling method.

4.1.3 To date only 'Preliminary Engineer's Logs' have been completed for six of the boreholes considered in this report and lack information supported by testing and full assessment of samples and geophysical data. Only 'drillers daily records' have been received for the seventh borehole, ML232-RC111. Groundwater monitoring installations have been constructed in these boreholes to allow for the monitoring of groundwater levels. Samples recovered from the ground are subjected to further testing in the laboratory. In-situ testing and geophysical logging carried out in the boreholes has not been processed and laboratory testing is underway. The draft factual report is not programmed to be complete until later in 2018. The use of the preliminary data and assessment of it at this stage is therefore subject to change based on the full complement of measurement taken in the boreholes. Preliminary conclusions regarding the ground conditions beneath the Whitmore Heath site can be drawn from preliminary data, observations and interpretation supported by desk study data.

4.2 Summary of findings of the fieldwork to date

4.2.1 Initial assessment indicates that the geological sequence and ground conditions are generally as predicted (based on the desk study). Sandstones, conglomerates and mudstones belonging to the Wilmslow Formation and Chester Formation were encountered from shallow depths. Conditions typically comprise a weathered section of bedrock over extremely weak to weak rock.

4.2.2 Shallow superficial deposits encountered were scattered and thin. No significant depths of made ground were encountered.

4.2.3 The geological formations encountered and early assessment of ground water level are summarised below.

Wilmslow Sandstone Formation

4.2.4 The Wilmslow Sandstone Formation was encountered in boreholes ML231-RC123 and ML232-CR102, between Chainage 231+700 to 232+250. A weathered layer was encountered at the top of the Wilmslow Sandstone Formation. This commonly comprised residual sands and gravels with varying cobble content and occasionally clay was present. The weathered layer was present to a depth of between 6.5 and 11.5 m below ground level.

4.2.5 Below the upper weathered zone (6.5-11.5 mbgl), the Wilmslow Formation comprised extremely weak to very weak Sandstone. Mica was frequently present within the sandstone.

4.2.6 The base of the Wilmslow Formation was poorly defined.

Chester Formation

4.2.7 The Chester Formation underlies the north-western part of Whitmore Heath and conformably underlies the Wilmslow Formation in the south-eastern part of the site. The Chester formation was encountered in boreholes: ML231-RC123, ML232-CR102, ML232-CR106, ML232-CR107, ML232-CR108, ML232-RC111 and ML232-RC112.

4.2.8 The upper profile of the Chester Formation exhibits a weathered layer comprising residual sands and gravels with more competent material being encountered below. The weathered layer measures 3 – 4 m in thickness on top of Whitmore Heath (boreholes ML232-RC111 and ML232-RC112) with greater thicknesses measured down the eastern flank of Whitmore Heath, with the weathered layer measuring between 5 and 10 m (boreholes ML232-CR106, ML232-CR107, ML232-CR108).

4.2.9 The weathering in the Chester Formation is predominantly confined to an upper layer, however, in a borehole ML232-102 weathered material (soil) was encountered below rockhead, though only of limited vertical thickness.

4.2.10 Below the weathered zone, the Chester Formation comprises very weak locally extremely weak Sandstone and Conglomerate. Frequently the sandstone is micaceous. Mudstone beds were encountered infrequently. The base of the Chester Formation was not encountered in the investigation.

Ground water

4.2.11 Groundwater level monitoring undertaken to date has recorded the groundwater at approximately 109 and 111 m above Ordnance Datum. This should be reviewed following a further period of water level monitoring to account for seasonal variations.

4.3 Geotechnical Properties

4.3.1 The geotechnical properties have been assessed based on site observations, Standard Penetration Tests and an initial review of the downhole logging information.

4.3.2 In-situ tests (Standard Penetration Tests or SPT) in the weathered zone indicate that the relative density of the granular material is loose becoming dense with depth.

4.3.3 In situ testing values (SPT), applying correlations in weak rock, based on Cole and Stroud (1976), for the sandstones in the Wilmslow and Chester Formations indicate extremely weak[2] material at shallow depths (below the weathered zone) with a slight increase in strength with depth i.e. becoming very weak / weak strength in places. It is likely that some of the SPT's will have been detrimentally affected by the presence of

[2] For engineering purposes British Standard, BS 5930 (2015) defines extremely weak rocks as having unconfined compressive strength values of between 0.6 and 1.0MPa, very weak rocks between 1 to 5MPa and weak rocks between 5 and 25MPa.

cobbles but they give an indication of the consistency (strength) of the materials present.

4.3.4 The in situ testing and descriptions appears to suggest unconfined compressive strength similar to those encountered elsewhere in the Sherwood Sandstone Group in line with the desk study review.

4.3.5 The borehole walls held up unsupported to facilitate the geophysical testing. This supports the classification that this material is a weakly cemented rock below the weathered zone. Occasional fractures of the rock mass have been observed in the core samples and can be seen in situ with the televiewer but a generally 'massive' (infrequent joints) formation was observed.

4.4 Tunnelling Assessment Informed by Ground Conditions

4.4.1 The elevation of the crown ranges between approximately 133 to 135m OD and the soffit elevation ranges between 124 to 126m OD, between Chainage 232+217 and Chainage 232+907. The ground conditions encountered across this interval (in boreholes ML232-RC106, ML232-CR107, ML232-RC111 and ML232-RC112) comprise extremely to very weak sandstone and or conglomerate rock.

4.4.2 The Whitmore Heath topography, tunnel alignment, rockhead and groundwater profile based on preliminary ground investigation findings are shown on the cross section included as Figure 4 (varying horizontal and vertical scale). Figure 5 shows an illustrative cross section perpendicular to the tunnel across Whitmore Heath at the same horizontal and vertical scale to illustrate variation in topography west to east and the tunnel in cross section. Borehole ML232-RC112 is shown on this cross section as representation of the ground investigation findings to date.

4.4.3 Initial assessment of the ground and groundwater conditions confirms the assumptions made at the initial preliminary design phase to be reasonable with respect to Tunnel Boring Machine excavation and dewatering assumptions and these are considered to be conservative with respect to surface settlement assessment.

4.4.4 The encountering of rocks classified as extremely weak to weak is within the range of values anticipated and has not adversely changed the basis of preliminary design assumptions with respect to tunneling.

5 Glossary

5.1.1 Conglomerate - a coarse-grained sedimentary rock composed of rounded fragments embedded in a matrix of cementing material.

5.1.2 Downhole geophysical (logging) – use of geophysical techniques to assess in situ rock properties

5.1.3 Downthrow (with respect to a fault) - the side of a fault that appears to have moved downward relative to the other side.

5.1.4 Drillers Daily Records – records prepared by the driller for a borehole; records driller's assessment of ground, progress, in situ test results, groundwater observations and any other notable observations.

5.1.5 Geological Fault – a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement as a result of rock-mass movement.

5.1.6 Glacial Till – glacial sediment deposit derived from the erosion and entrainment of material by the moving ice of a glacier.

5.1.7 Groundwater level monitoring – measurement of ground water levels in standpipes and piezometers that have been installed in a borehole.

5.1.8 Hydrogeology – the area of geology that deals with the distribution and movement of groundwater in soil and rocks.

5.1.9 Micaceous - term used to describe a rock containing the mica, typically a shiny platy mineral.

5.1.10 Permeability testing – laboratory or in situ test to measure the rate of fluid flow through the ground (soils and rocks).

5.1.11 Point Load Test - Laboratory rock strength test.

5.1.12 Preliminary Engineer's Logs - the record of the soil and rock descriptions undertaken and include estimated relative density and strength data based on observations and in situ SPT. The logs have not been adjusted to reflect laboratory testing or geophysics.

5.1.13 Rotary Core Drilling – drilling technique utilising a rotary drilling rig to sample rock.

5.1.14 Standard Penetration Test - in situ testing method used to determine the strength of subsurface ground.

5.1.15 Televiewer - is tool lowered down the borehole to record images of the in situ ground conditions. Optical and acoustic versions commonly used.

5.1.16 Unconfined (Uniaxial) Compressive Strength - The maximum axial compressive strength of an unconfined sample of rock stress that a cylindrical sample of material can withstand before failing.

5.1.17 Weathering (of rock) - the breakdown of rocks by the action of rainwater, extremes of temperature, and biological activity. It does not involve the removal of rock material.

6 Acronyms

6.1.1	BGS	British Geological Survey
6.1.2	CA	Community Area
6.1.3	GI	Ground Investigation
6.1.4	mOD	Metres (above) Ordnance Datum
6.1.5	MPa	Mega Pascal
6.1.6	PLT	Point Load Test.
6.1.7	TBM	Tunnel Boring Machine
6.1.8	SPT	Standard Penetration Test
6.1.9	UCS	Unconfined (Uniaxial) Compressive Strength.

7 References

1. Historic OS Mapping Sheets at scale 1:10,000 (Year 1900, 1925, 1947, 1954, 1967, 1968, 1981 and 1982) and at scale (Year 1882, 1900, 1924, 1959, 1960 and 1980)
2. BGS Borehole at the Rectory (Borehole BGS ID: 792519 and BGS Reference: SJ84SW132)
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7. British Standard BS 5930:2015, Code of practice for ground investigations.

8. P.G.Yates, The material strength of sandstones of the Sherwood Sandstone Group of the north Staffordshire with reference to microfabric, Quarterly journal of Engineering Geology (1992), Volume 25, p 107-113

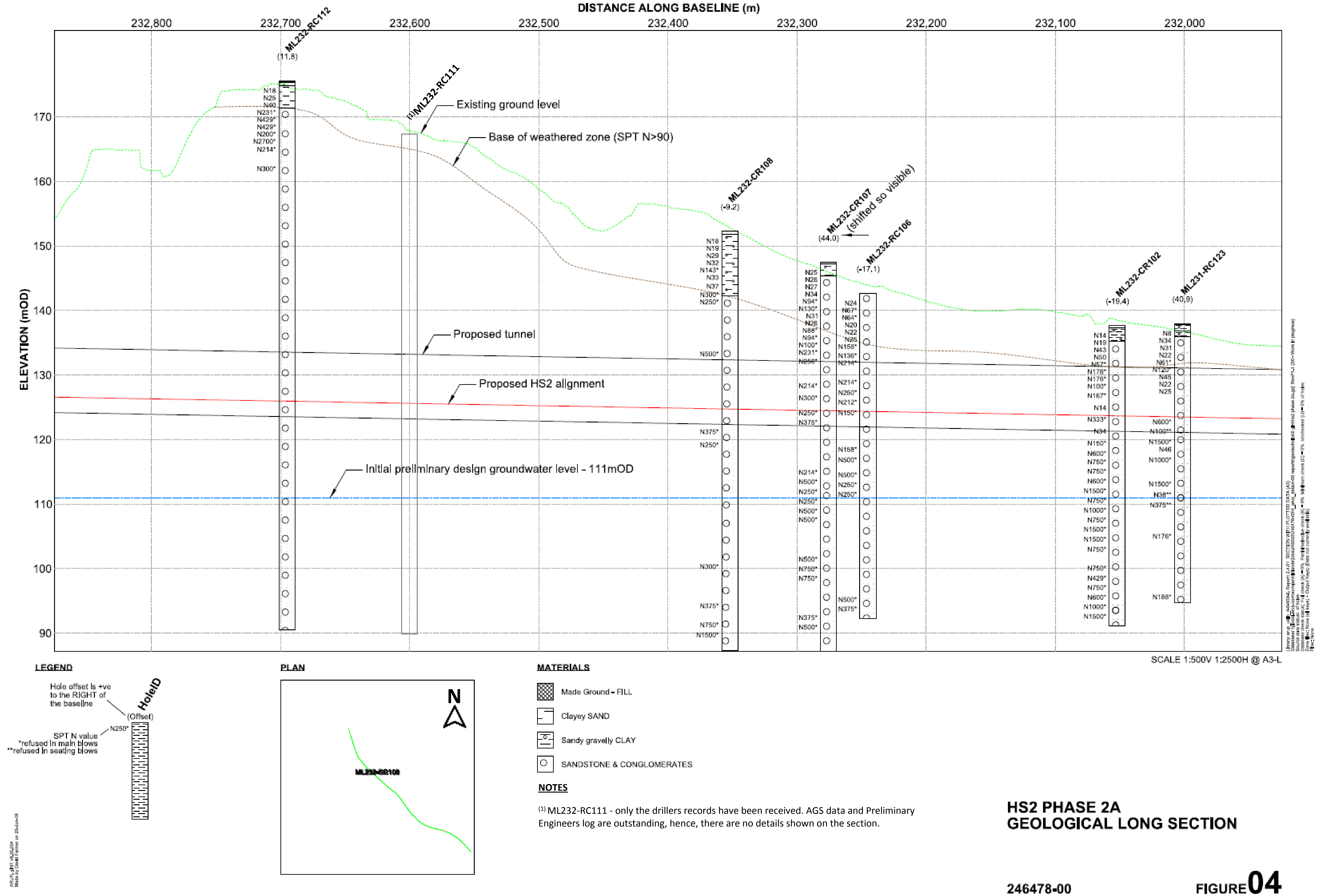

Figure 4 Cross Section along the Tunnel alignment

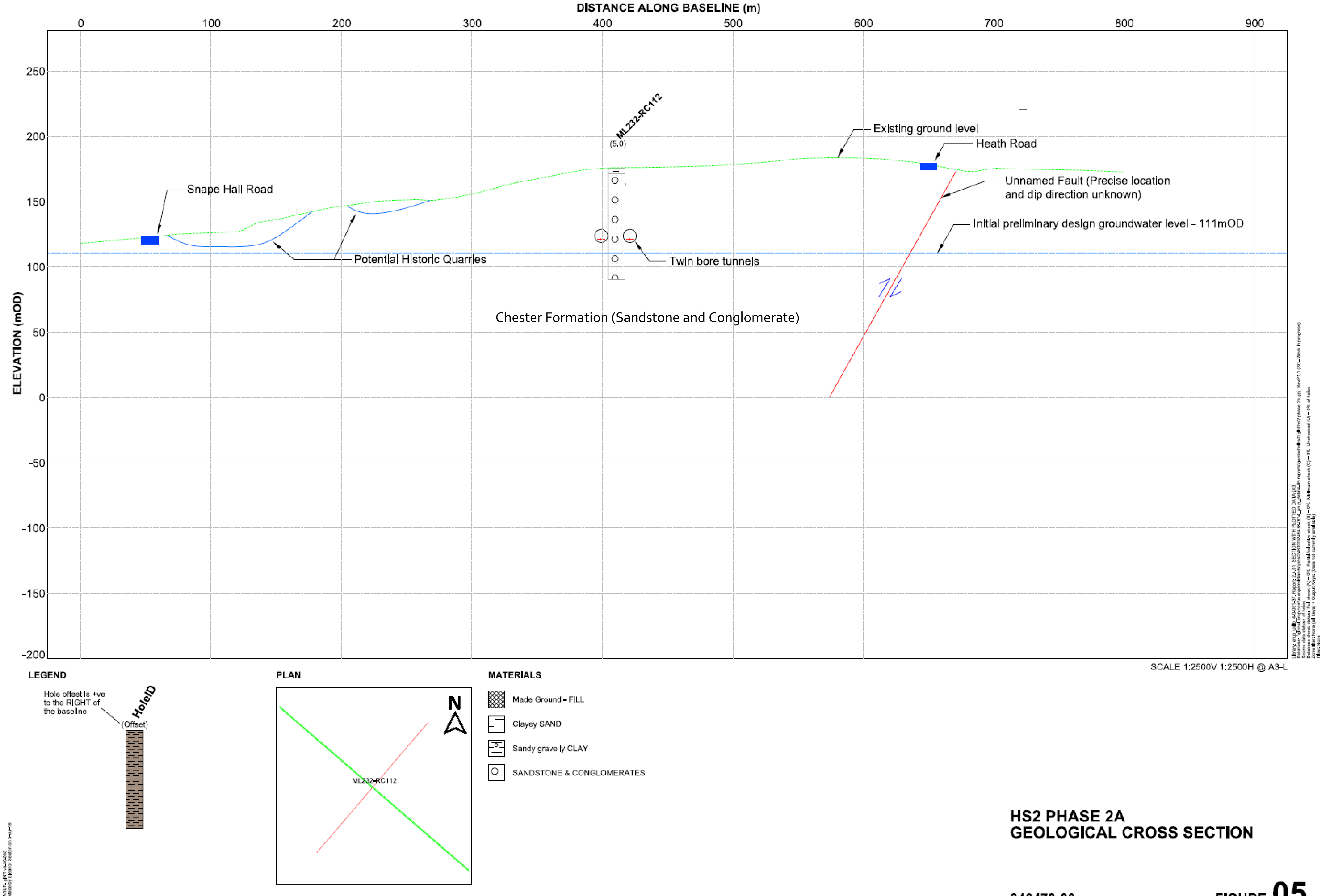

Figure 5 Cross Section perpendicular to Tunnel alignment