East Anglia ONE North and East Anglia TWO Offshore Windfarms

HDD Verification Clarification Note

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Applicable to East Anglia ONE North and East Anglia TWO

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Riggall & Associates Ltd.

FEASIBILITY REVIEW OF HORIZONTAL DIRECTIONAL DRILLING (HDD)

East Anglia TWO and East Anglia ONE North Offshore Windfarm Projects’ Landfall, Thorpeness, Sussex

Client: Royal HaskoningDHV

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CONTENTS

1. INTRODUCTION

Royal HaskoningDHV, on behalf of East Anglia TWO Limited and East Anglia ONE North Limited have requested that Riggall & Associates provide a review of the feasibility of using Horizontal Directional Drilling (HDD) at the landfall of the East Anglia TWO (EA2) and East Anglia ONE North (EA1N) offshore windfarm projects (the Projects).

This report has been produced by Riggall & Associates, an independent firm providing technical advice on HDD solutions to developers and contractors. Riggall and Associates were set up in 2005 as a geotechnical consultancy specialising in HDD and have worked on over 200 HDD projects. The company specialises in feasibility studies, hydrofracture modelling, drill force modelling, detailed design and planning of HDD's. Riggall & Associates have extensive experience of long-distance HDD's, up to 4.6km, having been involved in World Record length HDD projects in 2005, 2011 and 2017. Tim Riggall, author of this report, has an academic background in geology (BSc Hons, 1990) and geotechnical engineering (MSc with Distinction, 2008) along with 30 years geological experience. Over the past 20 years he has specialised in HDD.

The landfall HDD's are to be located north of Thorpeness with planned lengths of up to 2000m.

Riggall & Associates have previously conducted two site inspections at the HDD locations; in July 2017 as part of site selection for the Projects undertaken by Wardell Armstrong, and in August 2020 as part of further design studies for the Projects undertaken by Arup. This report includes the pertinent information from these studies and presents an up to date review.

2. INFORMATION REVIEW

The Applicants have provided a number of reference sources for this review and Riggall & Associates have also reviewed publicly available information including BGS mapping and borehole records were reviewed using the online BGS viewer at https://mapapps.bgs.ac.uk/geologyofbritain/home.html and the 1:50,000 series published map (Sheet 191 "Saxmundham").

2.1. Indicative HDD Route

Riggall & Associates have drafted indicative HDD Alignments and indicative design profiles for the landfall. The drawings have been produced specifically for this report as an aid for assessing the feasibility of the HDD's; they represent a potential option for the HDD but the final route and design may well vary from the design shown. The final route alignment and profile will be determined during detailed design using the results of ground investigations, offshore surveys, and engineering calculations for the HDD's that are typically undertaken pre-construction. The indicative designs by Riggall & Associates are shown on Drawing No. 20210104RA-C/01 in Appendix A.

The indicative designs are shown to a length of 1.7km in order to exit in water depths typically suited to a range of cable lay vessels, however the Applicants have allowed for the maximum length of the HDD to be 2km for the purpose of the initial design envelope.

2.2. Achievable HDD Lengths

HDD's, including landfalls, of the lengths proposed for the Projects have been drilled on many occasions, with the longest "single shot" HDDs currently being just over 3km in length. Twenty years ago a 1km HDD was considered a long HDD, with the first 2km HDD's being completed in 2001. Since then, the frequency of longer HDD's has increased, along with the capability of the HDD rigs, drill pipe, and downhole tooling. Table 2 gives examples of some longer landfall HDDs, most of which Riggall and Associates have been involved in.

Table 1. HDD Landfalls of longer length

Project name	Location	Country	Length (m)	No. of Drills	Completed	Type
BHPB	Port Campbell	Australia	1565	1	2003	Landfall
Hangzhou Bay	Jiaxing	China	1750	2	2003	Landfall
NOEL	Trinidad	Trinidad	1760	1	2005	Landfall
Pohokura	New Plymouth	NZ	1850	2	2005	Landfall
PPC-1	Sydney	Australia	2000	1	2008	Landfall
Qatif	Qatif	Saudi Arabi	2100	1	2009	Landfall
Dolwin 1	Hilgenriederseil	Germany	1150	2	2011	Landfall
Westermost Rough	Tunstall, Holderness	UK	1015	1	2013	Landfall
Dudgeon	Weybourne	UK	1170	2	2015	Landfall
Ebb Tide Release	Yamba	Australia	1670	1	2016	Outfall
Caithness-Moray	Portgordon	UK	1650	3	2017	Landfall
EA1	Bawdsey	UK	1020	2	2018	Landfall
EA3	Bawdsey	UK	1020	2	2018	Landfall
Tangguh	Bintuni Bay	Indonesia	2065	3	2018	Landfall
Moray East	Boyndie Bay	UK	1000	3	2019	Landfall

2.3. Geology

BGS 1:50,000 scale mapping indicates that the superficial deposits between the HDD entry point and the cliff line are outwash sands and gravels, and chalky pebbly glacial till (diamicton) of the Lowestoft Formation. The sands and gravels will typically be excavated at the HDD entry pit and a thin layer of glacial till (3-5m vertical thickness) will be the first strata encountered in the drill.

Interpretation of the solid geology beneath the superficial deposits between the HDD entry point and the cliff line relies on interpolation between outcrops and boreholes in surrounding areas. The solid geology is expected to comprise Crag Group overlying London Clay, that in turn overlies Chalk. The London Clay is unlikely to be encountered in the HDD, and the Chalk, indicated as 90m below ground level on BGS mapping, will not be encountered.

The borehole logs for BGS Boreholes TM46SE38 and TM46SE39 (See references; BGS Geology of Britain Viewer) indicate Chillesford Church Sand Member, a subdivision of the Norwich Crag Formation, as overlying the Crag Group. The borehole locations are approximately 1200m west and 800m north of the HDD entry site and this unit could be present at the site.

The Crag Group contains a number of subdivisions that are expected to be present at along the HDD route. The upper unit is the Red Crag Formation; fine to coarse-grained, poorly sorted, cross-bedded, abundantly shelly sands. Sub units belonging to the Sizewell Member and Thorpeness

Member may be present in the Red Crag Formation, but from a drilling perspective they will be indistinguishable.

The lower unit in the Crag Group is the Coralline Crag. It is composed of carbonate-rich skeletal sands. The sand fraction is moderately to poorly sorted medium-grained sand, the mud content is low. The Coralline Crag is typically weakly cemented, however some localities were sufficiently well cemented for it to have been used as a local building stone.

Based on the BGS mapping it is considered that the Coralline Crag is in a band trending northeast to southwest and possibly sub-crops in this area. The crag is exposed in the offshore area to the east as well as to the south of Thorpeness at North Warren. Based on the exposures it appears to have a gently dip towards the northeast and may be at just below 0m ODN at the HDD location.

Descriptions in literature indicate that the Red Crag is either “banked” against the Coralline Crag, or overlies it. An interpretation of the geology along the route of the proposed HDD alignment is shown on the sectional drawing on Drawing No. 20210104RA-C/01 in Appendix A. Ground investigations will be undertaken along the route to verify the position of the boundaries between the geological units.

Figure 1. **LEFT: Coralline Crag Outcrop (pink), and Subcrop (orange), from published geology map.**
RIGHT: Coralline Crag with 100m buffer (purple) (based on Figure 7.7 of the Projects’ Environmental Statement)

The Crag Group deposits (including the Coralline Crag) rest on the London Clay Formation. The publicly available BGS boreholes surrounding the site indicate that the London Clay is at approximately -50m ODN. However, this differs to the base of Crag contour map shown on the 1:50,000 series published map, that shows the base of the Crag at -20 to -30m ODN. The position shown on the sectional drawing in Appendix A assumes the shallower depth of -20m ODN beneath the HDD entry site, deepening to -30mODN at the offshore end of the HDD route. Ground investigations will confirm the true depth to the London Clay, however, unless it is significantly shallower than expected, the HDD will not be drilling within the London Clay.

The BGS mapping of the offshore outcrops of the Coralline Crag and GIS data (Figure 1) show different distributions for the outcrop. For indicative HDD designs, in Appendix A, the larger outcrop has been assumed, along with a 100m buffer zone.

2.4. Suitability of Geology for HDD construction

Based on the published and publicly available information, the ground conditions along the indicative HDD route are suitable for HDD.

Ground investigations will be undertaken to verify the expected conditions including the position and strength of the various strata. Key considerations for HDD design for each unit are discussed in the sections below, along with potential mitigation measures.

2.4.1 Glacial Till

The HDD at the landfall will initially drill through a short length of chalky pebbly glacial till that is considered to be silty sandy Clay. The length drilled in the Glacial Till is expected to be approximately 30m to 50m. Glacial Tills are routinely drilled throughout the UK; the borehole is typically self-supporting in the clayey soils. In rare cases where there are concentrations of cobbles or boulders, the bore may need to be cased, however cobbles and boulders in Glacial Till are infrequent in Suffolk.

Ground investigations will assess the Glacial Till along the HDD profile to establish whether temporary casing will be required, but it is very rarely required in Glacial TIll.

2.4.2 Chillesford Church Sand Member

Where ground investigations show that this unit is present at the HDD alignment, it will be encountered from approximately 30m to perhaps 80m drilled distance. In publicly available BGS boreholes near the site, the Chillesford Church Sand Member (CCSM) is described as a moderately to well sorted fine to medium grained sand with interbeds of silty clay.

Based on the borehole descriptions and information on pits in the Norwich Crag, the CCSM is expected to be medium dense to dense and self-supporting in near vertical faces. Ground investigations at the landfall will determine if this Member is present. It is expected to form a stable HDD borehole, and it is noted that sands are routine drilling for HDD projects.

Ground investigations will assess the CCSM along the HDD profile to establish whether temporary casing will be required through the section.

2.4.3 Red Crag

The HDD is expected to be in Crag Group deposits from 50m drilled length, up until 110m drilled length. The Crag in this section of the bore is expected to be medium dense to dense fine-grained shelly, glauconitic and micaceous sands with flint gravel. The Crag along this part of the Suffolk coast forms steep cliffs that collapse when undercut by wave action. This indicates that they are highly likely to be self-supporting when the HDD is reamed to the final diameter.

Ground investigations will assess the Red Crag along the HDD profile to establish whether temporary casing will be required through the section, however it is not expected to be needed.

Based on the BGS geological mapping, Red Crag is likely to also be encountered from 1300m until the end of the HDD where it exits through what is likely to be a thin layer of seafloor sediments. The Red Crag drilled in this section of the HDD is likely to be similar to that in the initial section of the HDD, however the bore will be supported by drilling fluid through this length and casing is not required.

The main consideration in this final section of bore is the loss of drilling fluid into the surrounding ground, potentially extending to the seafloor. This potential can be evaluated by hydrofracture modelling, where the calculated drilling fluid pressures for the profile can be compared to the pressure at which the ground is fractured. This hydrofracture pressure is calculated by formulas that use soil strength parameters derived from laboratory testing of samples recovered from the ground during ground investigations. The HDD drilling depth and profile can be optimised to defer the loss of fluid and breakout, but it is inevitable that at some point losses will occur, particularly as the HDD curves upwards to the exit.

Loss of fluid to surrounding ground, and eventually to the seafloor, is present on all HDD landfalls. The use of environmentally friendly drilling fluids (such as bentonite) and drilling with a minimum practical flow rate of the drilling fluid are the main mitigation methods.

The gravels present in the Red Crag may not be completely transported from the hole by the drilling fluid, rather they may accumulate in sections of the hole and need to be physically cleaned from the hole. Complete trips out of the HDD bore with the drilling bit or reamer (cleaning trips) may therefore be utilised at times during the HDD. This is a standard practice to ensure that all cuttings are removed from the bore, but the proactive use of cleaning trips will ensure that drilling equipment does not become stuck in the bore.

Research indicates that there is an identified gravelly bed at the base of the Red Crag; ground investigations will provide further information on whether it is presence. It is preferable for the HDD to avoid identified gravel beds if possible, otherwise the HDD bores may require additional cleaning during the HDD.

The presence of flint gravel within the Red Crag may also cause increased wear on drilling equipment. The ground investigations will therefore allow the HDD contractor to ensure that HDD equipment is best suited to the ground conditions, and monitor the condition of drilling bits for cleaning trips or scheduled checks.

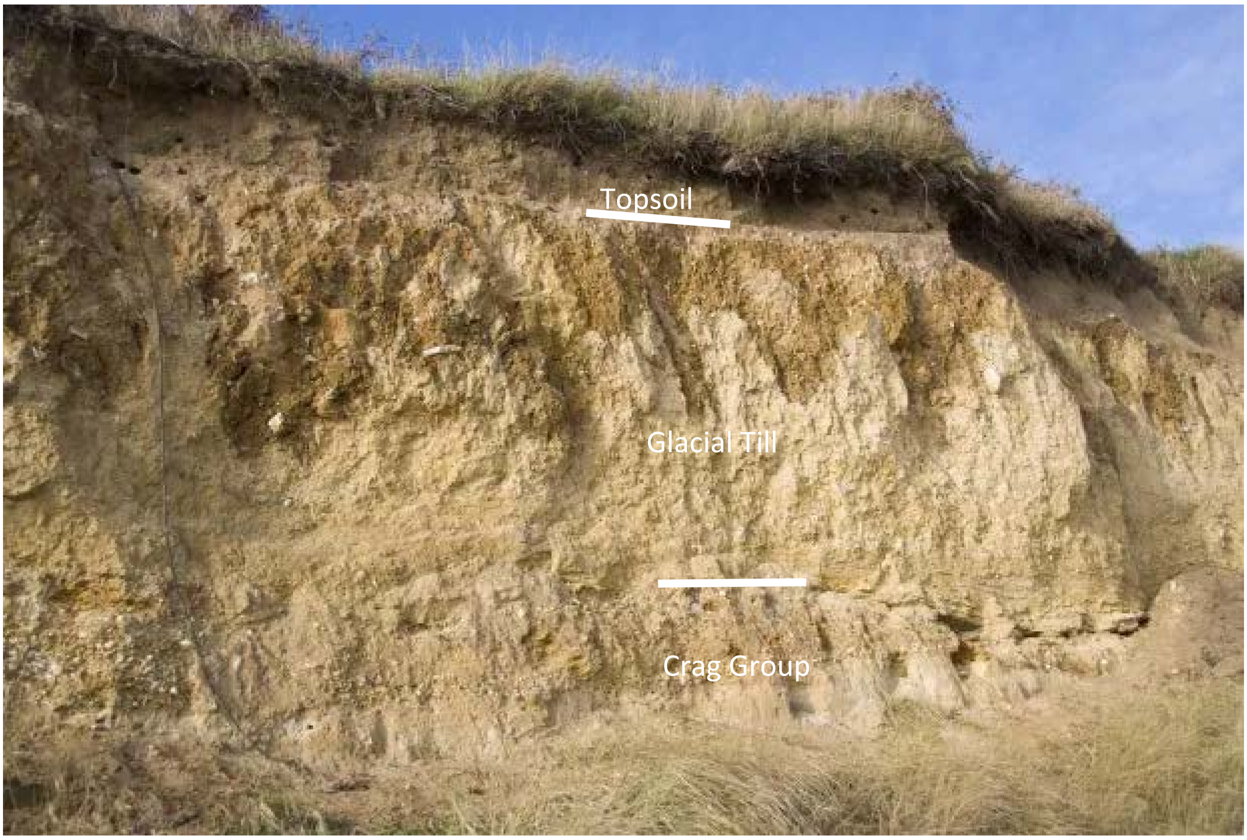


Figure 2. Coastal Cliff at Thorpeness with interpreted lithology. Credit UK Fossils Network website, https://ukfossils.co.uk/dscf4529/. Annotated by Riggall & Associates

2.4.4 Coralline Crag

The HDD is likely to be drilling within the Coralline Crag from 110m until 1300m drilling distance (but not exiting within the visible extents of the Crag). The Crag is expected to provide ideal conditions for HDD because it is typically weakly cemented and is expected to allow good rates of progress while also forming a stable bore. It is similar to calcarenite formations drilled in the U.A.E. to lengths exceeding 3km.

The Coralline Crag has been used as building stone in the local area. Strength testing of samples from ground investigation boreholes will determine the type of HDD drilling bit required for the HDD in this section of the bore. It should be noted that HDDs commonly drill through ground of varying strengths; the drilling bit can be tripped out of the hole and changed to suit the ground conditions encountered.

Balson and Humphreys (1986) noted the presence of vertical joints within the Coralline Crag that were generally c.5 cm wide and 2-3 m high. Some of the fractures appear to have remained open. These will not pose a problem for bore stability, being vertically oriented, but there might be temporary fluid losses as the drilling bit passes through them. When the bit has passed, the drilling fluid in the fractures will gel to seal the fractures. If persistent losses occur there is a wide range of stop-loss materials that can be added to the drilling fluid to seal the fractures.

The fossiliferous nature of the Coralline Crag, combined with zones that may only be weakly cemented, may result in gravel sized fragments not being broken up by the bit and accumulated as gravel beds in the bore. The HDD contractor will be proactive in monitoring drilling forces and undertaking cleaning trips, particularly in the first HDD. After the first HDD has been completed the HDD contractor will have established whether accumulations are present and how frequently cleaning trips are required.

Figure 3. Photo of Coralline Crag quarry at Crag Farm Pit near Sudbourne. Credit UK Fossils Network, https://ukfossils.co.uk/dscf0515/

2.4.5 London Clay

The HDD is not expected to drill within the London Clay as it is likely to be at a greater depth than is acceptable for the offshore export cable design.

The potential for hydrofracture, resulting in losses of fluid to the surrounding ground and potentially to the surface, is increased in London Clay if the clay cuttings agglomerate while they are being transported in the drilling fluid. The agglomerations can plug the hole, elevating the pressure of the drilling fluid down hole and forcing the fluid into the surrounding ground.

London Clay is frequently drilled in southeast England and the key to mitigating the risks associated with it are regular cleaning trips to size the hole, along with formulating the drilling fluid to counteract the properties of the clay. Clay inhibiting additives in the drilling fluid are the primary method of sealing the clay and prevent swelling. The use of real time annular pressure monitoring behind the drill bit will also warn of increasing downhole pressures to inform of the need for cleaning trips.

The potential for stuck equipment in the London Clay is avoided by standard procedures of monitoring drilling forces, tailoring the drilling fluid to the clay, and ensuring the cuttings are removed from the bore.

2.5. Potential for impact of the HDD on Aquifers

A branch of HDD has developed to specifically drill in aquifers, particularly for mineral water extraction, and for desalination plants. An example is the Mataro project in Spain, where Catalana de Perforacions completed a fan of 30 No. of HDD's, each of 900-1000m length. The HDDs were drilled in permeable sediments and lined with perforated casing to provide intakes for a water desalination plant.

Another of Europe's largest HDD contractors has termed drilling through permeable ground for water extraction as 'HDDW' and have completed a number of projects, however the method is simply HDD with installation of a filter pipe rather than a solid pipeline or duct.

Tim Riggall has been involved in a number of projects in which aquifers have been drilled through sucessfully, including Myall Avenue (1000m) and Sublime Point (1225m) in Katoomba, Australia, Huelva (1400m) in southern Spain, Biriatou (575m) through limestone solution streams on the border of France and Spain, and Exedown Road Kent (450m) through the white chalk (a principal aquifer).

Loss of drilling fluid into any aquifer is counterproductive to efficient drilling, the drilling fluid returns are required in order to transport cuttings from the bore and lubricate the drilling equipment and the drilling fluid is recycled and reused to reduce the use of raw materials. Consequently, fluid losses are actively avoided during the HDD. The drilling fluid engineer on the site carefully monitors the fluid usage in the recycling system and will quickly identify if fluid is being lost to the ground. If fluid loss is identified there are a number of measures that can be taken to seal the bore, including;

- Modifying the drilling fluid properties to increase the effectiveness of the bentonite clay filter cake that lines the wall of the borehole;
- Addition of stop-loss materials to bridge and seal larger voids in the soil; or
- Modifying the mud weight (drilling fluid density) to either balance or counter the groundwater pressure depending on the ground conditions.

Modification and control of drilling fluid parameters to drill in permeable ground is a well-established science, having been refined and researched to ensure that oil and gas wells are drilled without damaging the reservoirs they are targeting.

The bentonite used as the base for the drilling fluid is a naturally occurring, non-toxic clay. Any losses into the aquifer will not contaminate the aquifer. There is a range of environmentally inert drilling fluid additives that can be used for modifying the properties of the drilling fluids to suit the ground conditions encountered. Ground investigations will provide further information on the permeability of the ground and allow selection of additives suitable to ground conditions and use in aquifers.

Studies by hydrogeologists undertaken pre-construction will determine the risk of any losses affecting any abstraction points near the landfall. Studies for other landfall sites have indicated a low risk because aquifer flows are generally seaward, taking any turbidity plumes away from abstraction points, and because the HDD is predominantly beneath the sea, where there is no abstraction.

East Anglia TWO Limited and East Anglia ONE North Limited have undertaken a hydrogeological risk assessment for the Projects' HDD works at the landfall (Planning Inspectorate document reference ExA.AS-12.D6.V1). This concludes that there will be no degradation of the aquifer.

2.5.1 Aquifer in the Red Crag

Examination of BGS borehole records of bores and wells surrounding the landfall, indicate that abstraction in the local area is typically from the Red Crag. BGS Borehole record TM46SE67 is located at Ted’s Barn, approximately 75m from the HDD entry points. The records for the 4ft diameter well indicate it drew water from between 10-14m depth below ground level. This suggest that the aquifer is in the lower 4-5m of the Red Crag where it rests on the underlying stronger, cemented Coralline Crag.

East Anglia TWO Limited and East Anglia ONE North Limited are aware of a private water supply approximately 550m north of the potential HHD bore locations as shown in Appendix A. It is understood that this feeds five properties at and around Ness House, including Wardens Trust (a charitable organisation that offers recreational and outdoor facilities for children and adults with disabilities). Data made available on the supply indicates that the water level in the well is at 11.7m, with the depth of the well being 13.1m.

Planned ground investigations will test the permeability and position of groundwater along the onshore section of the HDD. Drilling fluids are designed to seal permeable ground, the naturally occurring bentonite clay used as the base for the drilling fluid, lines the borehole wall, preventing fluid loss and groundwater ingress. The permeability of the Crag appears to be from interstitial flow (flow through the pores or spaces between the sand grains), rather than from flow along fractures, and the bentonite drilling fluid alone is designed to seal the bore.

If the ground investigations indicate that flow is through fractures in the ground, the mitigation will be to add stop-loss materials to the drilling fluid to seal the fractures. There are a wide range of environmentally inert stop-loss additives available in the industry that can be utilised.

Ground investigations will assess the properties of the aquifer to establish whether temporary casing will be required through the section.

2.5.2 Aquifer in the Coralline Crag

Based on published descriptions of the Coralline Crag, where significant groundwater flows exist within the Crag, then they are likely to be along fractures and fissures rather than interstitial flows. Ground investigations will examine the permeability of the Coralline Crag through permeability testing and groundwater monitoring to determine if significant flows are likely. Mitigation methods will depend on the volume of any losses; small losses may be addressed by adjusting the properties of the filter cake that lines the perimeter of the HDD bore, larger losses may require the use of stop-loss additives within the drilling fluid.

2.6. Stability of the cliffs

Representations have been raised as to whether vibrations from the HDD would affect the stability of the coastal cliffs where the HDD bores passes beneath them.

Based on observational experience and previous measurements, Riggall & Associates consider that vibration from the HDD will not pose a risk of collapse of the cliffs. The observational evidence is that HDD’s always have an entry pit, typically 2-3m in depth with steep sides, to start the HDD. The steep sides of the pit remain standing except where the ground conditions are very loose sand, peat, or very weak desiccated clay. The pit sides themselves are not weakened by vibrations caused by the drilling bit.

Tim Riggall's personal anecdotal evidence comes from the fact that when an HDD is exiting on a land-to-land HDD crossing, the drill bit cannot be felt or heard until it is at shallow than 5m depth. Given that waves crashing on the shore can be felt tens of metres away, it follows that vibration from the HDD will be significantly less than vibrations from the natural environment that reach the cliff.

Numerous HDDs have been drilled beneath sensitive man-made structures and coastal cliffs without any notable effects. HDD is a method that has been used to stabilise areas of landslip in the past by drilling drainage holes. Recent examples are the White Point Landslide in California, Albion Lower Colliery Tip in south Wales, and Holland on Sea, Essex.

Empirical evidence was provided on a recent landfall project where vibration monitoring was installed on a pipeline deemed sensitive to movement. Measurements were taken during pilot drilling and hammered casing installation. At a distance of 5m from the sensor, vibration levels were 1.0 PPV (mm/s) above baseline levels. At 10m distance from the sensor, the casing and pilot drilling were not discernible above the background vibration. The indicative HDD design, shown in Figure 4 as well as in the drawing in Appendix A, shows that the Project's HDD is approximately 11m below the base of the cliff, therefore vibration levels are not considered to be discernible above background levels at this depth.

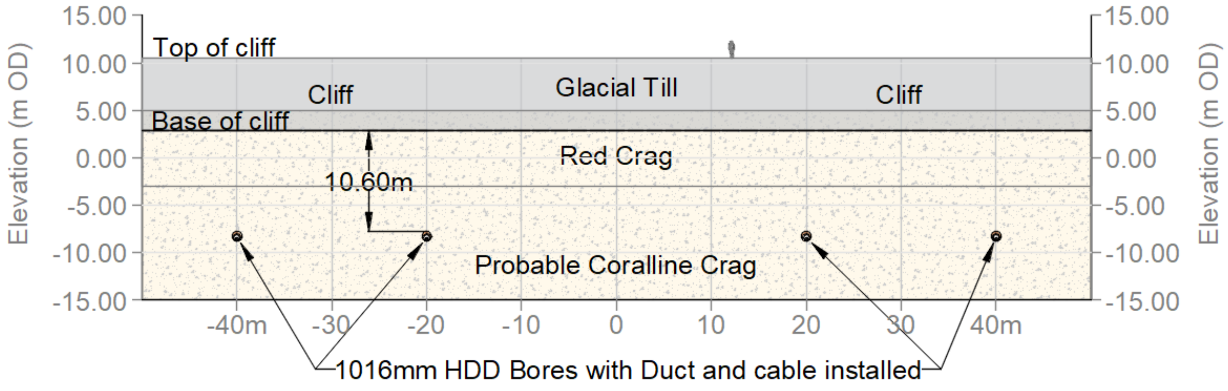


Figure 4. Detail showing the size and position of HDD's relative to the cliffs in true scale.

2.7. Hydrofracture modelling

Hydrofracture modelling is used to manage the risk of drilling fluid breakout or losses into the ground surrounding the HDD bore. It will be used to inform the detailed design of the HDD bore as well as the most suitable HDD drilling equipment and methodology.

An initial hydrofracture analysis has been completed on the indicative design, using parameters typical of a maxi-sized HDD rig, and assumed ground strength parameters as shown in Figure 5.

The ground strength parameters used are conservative, particularly in the Red Crag and Coralline Crag, because they assume there is no cementation. Ground investigations and the laboratory testing of samples taken during the investigations, will provide a better understanding of the ground strength parameters that can be expected on the HDD. This will allow more accurate hydrofracture modelling that can be used to inform the final design of the HDD's.

The modelling of the drilling fluid pressure uses the Power Law rheology model from API RP 13D 2003, while the hydrofracture strength modelling is calculated using the Delft equations as set out in US Army Corps of Engineers CPAR-GL-98-1.

GEOTECHNICAL PARAMETERS USED FOR HYDROFRACTURE
EA1N & EA2, 12.25" Bit, 18m deep design - 10/02/2021

Conservative Values Typical Values assuming no cementation								Weak Ground Values Typical Values assuming fractured and fissured with weaker infill materials							
Unit	Description	Measured		Angle of Internal Friction, ϕ	Undrained Cohesion c_u	Shear Modulus[1] G	Saturated Density δ	Unit	Description	Measured		Angle of Internal Friction, ϕ	Undrained Cohesion c_u	Shear Modulus[1] G	Saturated Density δ
		From	To							From	To				
		m	m	deg	kPa	N/mm^2	Mg/m^3			m	m	deg	kPa	N/mm^2	Mg/m^3
Unit 1	Loose SAND	0	15	32.0	0.0	6.0	1.7	Unit 1	very loose SAND	0	15	27.0	0.0	5.0	1.60
Unit 2	firm sandy CLAY	15	47	20.0	55.0	7.5	1.9	Unit 2	soft sandy CLAY	15	47	18.0	30.0	2.0	1.80
Unit 3	dense SAND	47	120	38.0	0.0	23.0	1.9	Unit 3	medium dense SAND	47	120	34.0	0.0	15.0	1.80
Unit 4	dense - Very dense SAND	120	410	39.0	0.0	30.0	2.0	Unit 4	dense SAND	120	410	38.0	0.0	23.0	1.90
Unit 5	Very Dense SAND	410	1290	40.0	0.0	38.5	2.0	Unit 5	dense SAND	410	1290	38.0	0.0	23.0	1.90
Unit 6	dense SAND	1290	457	38.0	0.0	23.0	1.9	Unit 6	medium dense SAND	1290	457	34.0	0.0	15.0	1.80

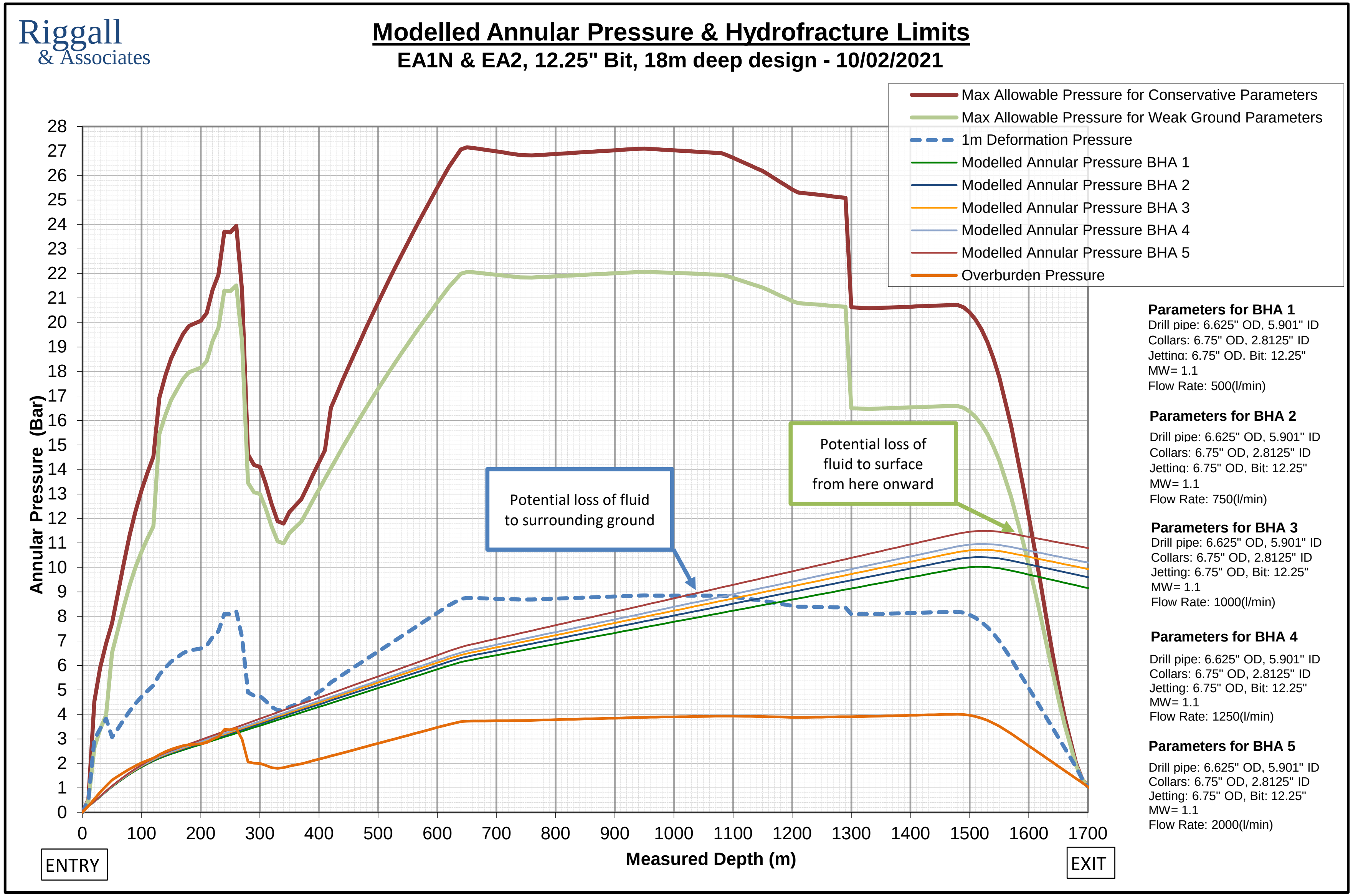
Notes: Values based on provided Geotechnical Information and typical values from other projects where applicable

Figure 5. Geotechnical Parameters used in the hydrofracture modelling.

The output graph in Figure 6 indicates that there is a very good margin of safety against drilling fluid breakout at the cliffs and intertidal area. The margin of safety is 7bar, typically 2 bar is used as a reasonable margin. Breakout of drilling fluid to the surface is not expected until 1580m onward, therefore in the final 120m of the drill.

The 1m deformation line on the graph provides an indication of when some fluid losses to the surrounding ground might begin. For the indicative HDD design it indicates potential for fluid loss to the ground from 1150m. The line is based on observations from previous drills – it tends to be reliable in clayey ground and sandy ground with interbedded clay layers. However, in ground that is entirely sandy losses to the ground typically occur at higher values than the 1m deformation line. Should ground investigations confirm the offshore geology is Coralline Crag and weakly cemented Red Crag, Riggall and Associates would not expect losses until much later, perhaps from 1500m onward.

Following completion of pre-construction ground investigations, the hydrofracture modelling will be updated and used to both refine the design and the HDD methodology. The drill bit size used in the modelling is a standard bit size, however the HDD contractors who drill HDDs of this length commonly use larger diameter bits to further reduce the annular pressure and increase the margin of safety against fluid losses and fluid breakout at the surface.



Modelled Annular Pressure & Hydrofracture Limits

EA1N & EA2, 12.25" Bit, 18m deep design - 10/02/2021

Parameters for BHA 1
Drill pipe: 6.625" OD, 5.901" ID
Collars: 6.75" OD, 2.8125" ID
Jetting: 6.75" OD, Bit: 12.25"
MW= 1.1
Flow Rate: 500(l/min)

Parameters for BHA 2
Drill pipe: 6.625" OD, 5.901" ID
Collars: 6.75" OD, 2.8125" ID
Jetting: 6.75" OD, Bit: 12.25"
MW= 1.1
Flow Rate: 750(l/min)

Parameters for BHA 3
Drill pipe: 6.625" OD, 5.901" ID
Collars: 6.75" OD, 2.8125" ID
Jetting: 6.75" OD, Bit: 12.25"
MW= 1.1
Flow Rate: 1000(l/min)

Parameters for BHA 4
Drill pipe: 6.625" OD, 5.901" ID
Collars: 6.75" OD, 2.8125" ID
Jetting: 6.75" OD, Bit: 12.25"
MW= 1.1
Flow Rate: 1250(l/min)

Parameters for BHA 5
Drill pipe: 6.625" OD, 5.901" ID
Collars: 6.75" OD, 2.8125" ID
Jetting: 6.75" OD, Bit: 12.25"
MW= 1.1
Flow Rate: 2000(l/min)

Figure 6. Output graph from hydrofracture modelling of the indicative design.

2.8. Outline HDD Methodology

The outline methodology for the HDDs is likely to be pilot hole drilling followed by forward reaming as far as is practical or efficient, then conventional pull reaming for the remainder of the bore.

2.8.1 Pilot Drilling

The pilot hole will be steered and surveyed using a wireline guidance tool located behind the drilling bit. There are two main types of tool available, Magnetic Guidance Systems, and Gyroscopic Systems. Typical accuracy of an MGS **at exit** on a 2km drill is +/- 5m laterally and +/- 2m vertically. For a Gyro tool at 2km the accuracy is typically +/- 3m laterally and +/- 2m vertically.

The accuracy of the guidance system at the cliff line is expected to be +/-0.25m vertical and horizontal for both systems. The position of the bore may also vary from the design due to deflection of the bit caused by changing ground conditions along the route. The effect of changing ground conditions is expected to result in deviation of <0.5m at any point. Therefore, the potential misalignment from design, at the cliffs, is the sum of guidance system accuracy and ground condition deviation, and is +/-0.75m. The HDD will be at approximately 11m below the base of the cliffs, therefore there is no risk that the HDD will inadvertently drill out through or near the cliffs.

During pilot drilling, the guidance system will also provide real time measurement of the annular pressure in the bore to ensure that drilling fluid pressures have sufficient margin of safety against drilling fluid breakout at the cliffs and intertidal area.

It should be noted that when the HDD has exited on the seafloor, the final exit position will be surveyed allowing calibration of the final as-drilled survey for the HDD. The calibration allows the position of the HDD to be determined at any point along the bore to an accuracy of +/- 0.10m.

2.8.2 Reaming

The reaming will be undertaken in steps of increasing bore diameter. There are two methods of reaming, forward reaming, where the hole is enlarged form the HDD rig out towards sea, and conventional (pull) reaming where the pilot hole exits to the sea bed and a reamer is connected and pulled from exit towards entry.

The use of forward reaming has benefits in allowing the drilling fluid to flow to the entry point where it can be recycled. Conventional (pull) reaming results in drilling fluid flowing to the exit point and therefore the sea.

A combination of the two methods can be used; for landfalls longer than 1km, forward reaming is commonly used until it reaches a point where it is becoming inefficient and the method is then switched to pull reaming to complete the bore. The distance at which this switch is made depends on a number of factors including the size and power of the HDD rig and drilling rods, the ground conditions on the route, and the size of the selected reaming steps. The methodology will be established pre-construction.

2.8.3 *Duct Installation*

The duct will be manufactured elsewhere and floated to the exit point for installation (termed "pullback") of the duct into the HDD bore. To begin pullback the seaward end of the drilling string is connect to the duct at a barge or workboat. The drilling rods are progressively removed by the rig at the entry point, pulling the duct into the hole and the process continued until the duct reaches the entry point.

It is also possible to use a pushed installation, where the duct is fabricated inland of the HDD site and a pipe pusher is used to feed the duct into the bore. For HDD lengths over 1km a pushed installation may require assistance from a winch positioned offshore and connected to the head of the duct to guide the head of the duct and prevent it buckling.

2.9. Environmental

2.9.1 *Drilling fluid losses*

For the majority of the length of the HDD, the risk of drilling fluid losses is confined to losses into the surrounding ground. Assessment and mitigation of these losses is addressed in Section 2.5.

The risk of breakout of drilling fluids at locations of reduced depth of cover, the base of the cliffs for example, can be managed by undertaking hydrofracture modelling (Section 2.7). The HDD is expected to be in Coralline Crag beneath the cliffs, and the strength of the Coralline Crag is expected to prevent any drilling fluid breakout at this point. The hydrofracture modelling assumes conservative ground strength parameters and shows a good margin of safety against breakout at the cliffs.

It is inevitable that breakout of drilling fluid to the seafloor will occur as the HDD approaches the exit. This risk is present on all HDD landfalls. Hydrofracture modelling can provide an estimate of where the breakout will first occur, the preliminary modelling in Section 2.7 indicates that it could occur from 120m before the exit position is reached. Use of environmentally friendly drilling fluids and drilling with a minimum practical flow rate of the drilling fluid are the main mitigation methods.

2.9.2 *Fluid spills*

Spills of bentonite or machinery fluids and oils from the HDD temporary working area are a potential risk. The risk is mitigated at the potential source by the use of bunded containers, encased stationary plant (generators, mud pumps etc), plant nappies under for refuelling and plant nappies placed beneath mobile machinery (excavators etc) while they are stationary. Further measures to intercept potential spills before they reach receptors are the standard site setup with geofabric underlay across the site, and bunding and silt fencing around the site perimeter.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. Riggall and Associates

This report has been produced by Riggall & Associates, an independent firm providing technical advice on HDD solutions to developers and contractors. Riggall & Associates specialise in HDD and have worked on over 200 HDD projects and have extensive experience of long-distance HDD’s, up to 4.6km, having been involved in World Record length HDD projects in 2005, 2011 and 2017. Tim Riggall, author of this report, has 30 years geological experience and over the past 20 years he has specialised in HDD.

Riggall & Associates have previously conducted two site inspections at the proposed HDD locations.

3.2. HDD Feasibility

Based on the available information, a landfall HDD of up to 2km in length in the expected ground conditions is achievable.

From a selection of previous landfall projects provided in Table 2, the ground conditions on EA1N and EA2 are likely to be closest to the calcarenites (weakly cemented sands) that were drilled on the Yamba Ebb tide project (1670m), and the Qatif project (2100m). Should the ground investigations indicate a considerable component of clay in the Red Crag, the completion of 3 drills in sand and clay on the Tangguh project (2065m) shows that mixed ground conditions can be drilled.

The HDD will predominantly be drilled in Red Crag and Coralline Crag, both of which are expected to provide good conditions for HDD.

The main geotechnical considerations for the HDDs are:

- the presence of loose sands in the ground drilled above mean sea level, if such conditions are found to be present, they would be temporary cased as mitigation;
- accumulation of gravels potentially causing hydrofracture or stuck drilling equipment. The mitigation method is to ensure drilling conditions are monitored and cleaning trips are undertaken proactively; and
- encountering high flow / highly permeable aquifers, with potential loss of drilling fluid. The mitigation method is to modify the drilling fluid properties to seal the HDD bore.

Real time annular pressure monitoring will be used to ensure drilling fluid pressures do not exceed ground strength when drilling beneath the coastal cliffs and the intertidal areas. Initial hydrofracture modelling in Section 2.7 of this report, shows a high margin of safety against drilling fluid breakout in these sensitive areas.

The annular pressure monitoring will also indicate if the HDD has encountered a significant aquifer, allowing the drilling fluid parameters to be tailored to seal and isolate the bore from the aquifer. Practically all HDD’s encounter groundwater, including aquifers, and a branch of HDD has developed specifically for installation of extraction wells within aquifers. The presence of aquifers and groundwater on this project will be managed with routine management of drilling fluid properties.

3.3. Ground Investigations and Offshore Surveys

Ground investigations will be used to confirm the assumed levels of geological strata and inform the detailed design of the HDD to enable it to drill in the most favourable strata where possible and ensure the optimum selection of equipment for the works.

Laboratory testing of samples from the ground investigations will inform ground strength parameters for hydrofracture modelling, design of drilling fluid formulation, and selection of drill tooling. In situ permeability testing and ground water monitoring will inform groundwater flows and characteristics for input into requirements for drilling fluid formulation including any stop-loss additive requirements.

Offshore surveys will provide high accuracy bathymetric information as well as sub–bottom profiling that identifies the three-dimensional distribution of strata using geophysical methods. This accurate ground model will be used to inform the detailed design of the HDD in the offshore sections of the HDD route.

References

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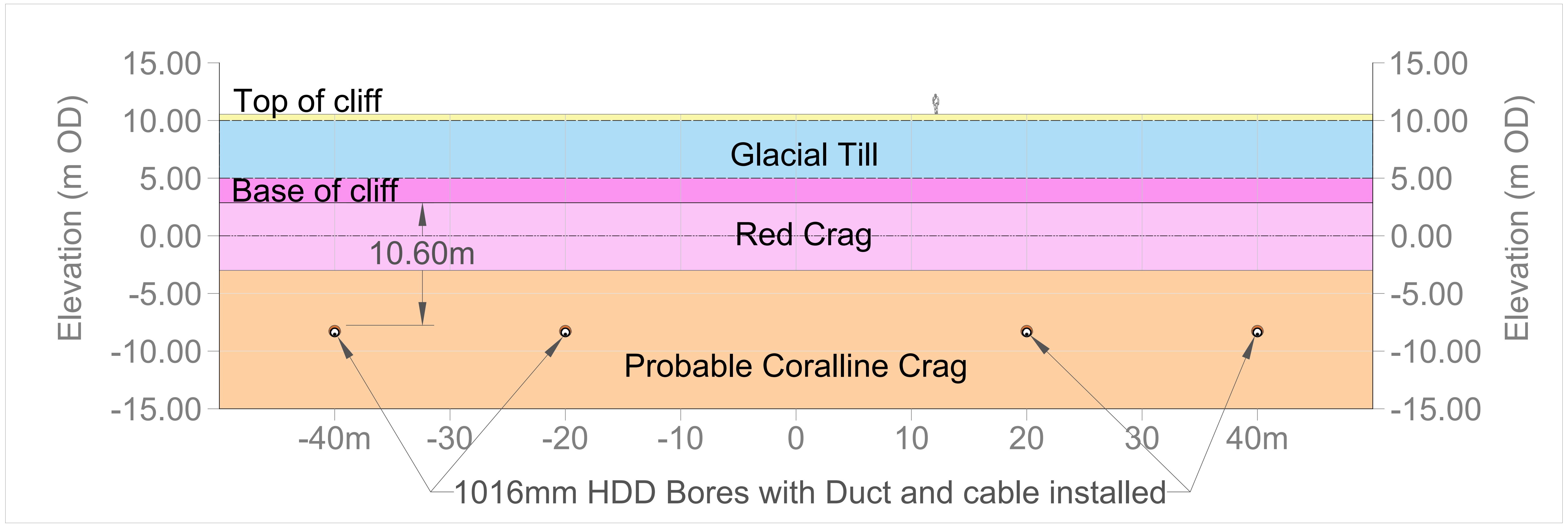
APPENDIX A – HDD INITIAL DESIGN DRAWING

PLAN VIEW OF INDICATIVE HDD ALIGNMENTS

INDICATIVE HDD LONG SECTION - VERTICAL EXAGGERATION 4V:1H



TRANSVERSE SECTION AT CLIFF LINE SHOWING HDD'S AT TRUE SCALE

NOTES

1. ALL DIMENSIONS, LEVELS AND CHAINAGES ARE IN METRES UNLESS OTHERWISE STATED.
2. HDD INDICATIVE DESIGNS ARE PROVIDED FOR INFORMATION ONLY. FURTHER GROUND INVESTIGATIONS ARE REQUIRED FOR DETAILED DESIGN OF HDD's.
3. TOPOGRAPHICAL PROFILE TAKEN FROM ARUP CONCEPTUAL GROUND MODEL (LiDAR DTM)
4. BATHYMETRY TAKEN FROM ARUP CONCEPTUAL GROUND MODEL
5. GEOLOGY IS BASED ON INTERPRETATION OF AVAILABLE BGS BOREHOLE LOGS, BGS MAPPING AND PUBLICLY AVAILABLE INFORMATION

DO NOT SCALE

Rev	Date	Description	By
B	10/02/2021	Updated for Rev02 of Feasibility Review	TR
A	10/02/2021	Draft for discussion	TR

Client
ROYAL HASKONING DHV

Scale	Drawn by	Date Drawn	Sheet Size
AS SHOWN	TR	10/02/2021	A1

Designed by	Checked by	Approved by	Date approved
TR			

Drawing Number	Issue
20210104RA-C/01	FR01

Project Title
EA1N & EA2 LANDFALL

Drawing Title
INDICATIVE HDD DESIGNS

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