From:	Gemma Keenan
To:	Tracey Williams
Cc:	Norfolk Vanguard; Sian Evans; rebecca.sherwood@vattenfall.com; "ruari.lean@vattenfall.com"; Josh Taylor (josh.taylor@wbd-uk.com)
Subject:	Norfolk Vanguard - Email 18 of 18 Deadline 1 Submissions
Date:	16 January 2019 15:22:16
Attachments:	ExA_AS;10.D1.8B Norfolk Vanguard Additional Submission - Landfall Info Sheet.pdf ExA_AS;10.D1.8C Norfolk Vanguard Additional Submission - Substation Info Sheet.pdf ExA_AS;10.D1.8A Norfolk Vanguard Additional Submission - Happisburgh HDD Feasibility.pdf

Dear Tracey

This is email 18 of 18 of the Applicant's submission for Norfolk Vanguard Examination Deadline 1.

We enclose the following documents:

- Norfolk Vanguard Additional Submission - Happisburgh HDD Feasibility
- Norfolk Vanguard Additional Submission - Landfall Info Sheet
- Norfolk Vanguard Additional Submission - Substation Info Sheet

Please could you kindly confirm receipt.

Best Regards

Gemma Keenan BSc, MIEMA, CEnv
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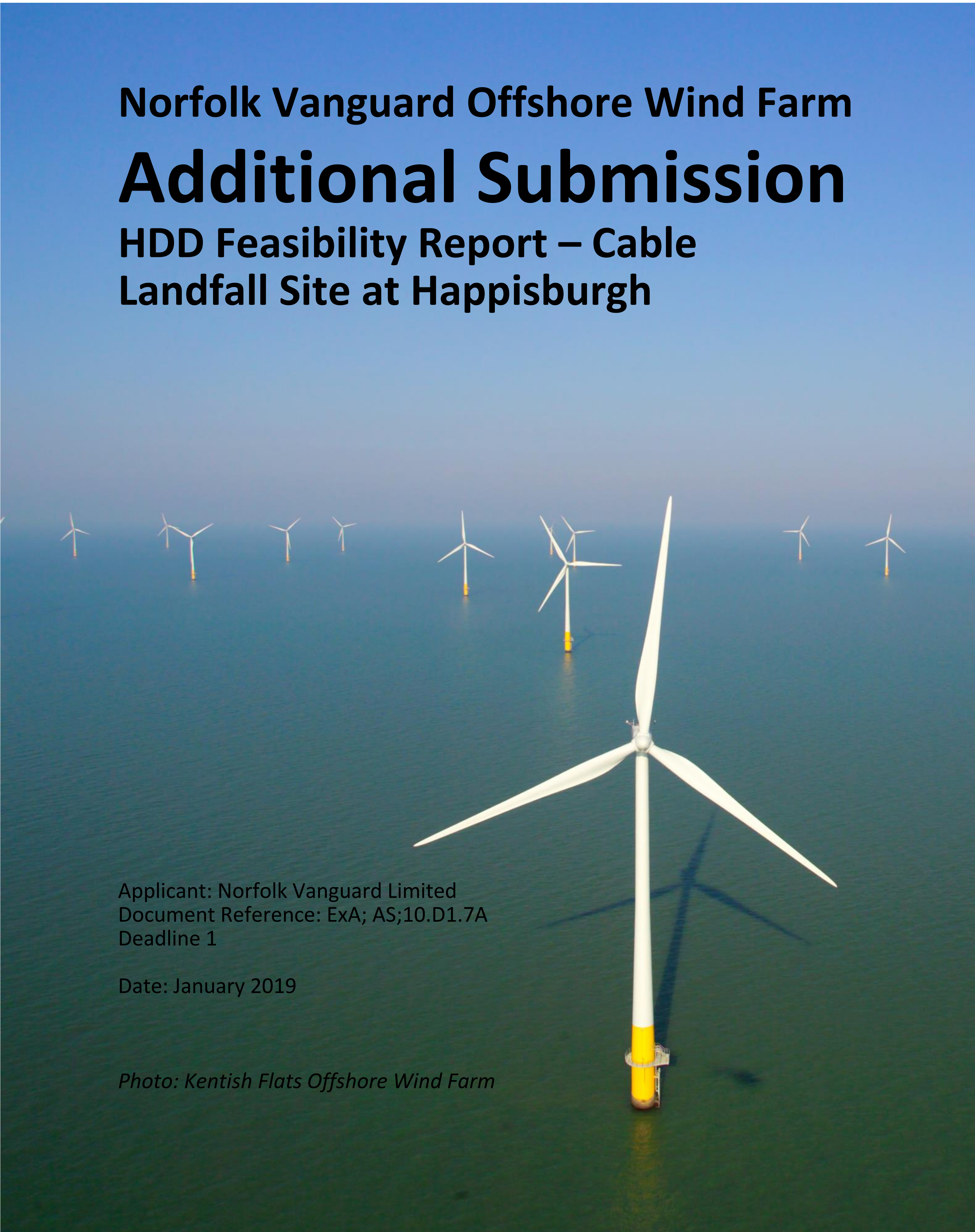

Norfolk Vanguard Offshore Wind Farm

Additional Submission

HDD Feasibility Report – Cable Landfall Site at Happisburgh

Applicant: Norfolk Vanguard Limited
Document Reference: ExA; AS;10.D1.7A
Deadline 1

Date: January 2019

Photo: Kentish Flats Offshore Wind Farm

Riggall & Associates Ltd.

HDD FEASIBILITY REPORT

Cable Landfall site at Happisburgh for Vanguard and Boreas Windfarms, U.K.

Client: Vattenfall Wind Power Ltd

Date of Issue: 26th February 2018

Report Reference No.: 20171201RA-FR01

Report Issue: Rev 02

Prepared by: Tim Riggall

Vattenfall Contract No.: 4500458862

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1. INTRODUCTION

1.1. Overview

Vattenfall Wind Power Ltd. ("Vattenfall") has sought expert opinion on the feasibility of Horizontal Directional Drilling (HDD) for proposed landfalls of offshore cables from the Vanguard and Boreas Windfarm Projects. Riggall & Associates have previously produced a HDD Feasibility Report (Report Ref. No. 20151001RA-FR01) evaluating 13 potential landfall sites along 47km of coastline. Following evaluation by Vattenfall, the Happisburgh location has been selected as the landfall site.

1.2. Scope of Work

Riggall and Associates have been invited by Vattenfall to examine documents related to the project. The aim of this report is to apply our knowledge and expertise in HDD, geotechnical engineering and geology in assessing the feasibility of various HDD options at Happisburgh.

The four options that Vattenfall wish to evaluate are as follows:

- Short HDD's exiting on the beach for 4 No. of HVDC cables
- Long HDD's exiting beyond 5m water depth for 4 No. of HVDC cables
- Short HDD's exiting on the beach for 12 No. of HVAC cables
- Long HDD's exiting beyond 5m water depth for 12 No. of HVAC cables

1.3. Reference Documents

The following documents and information sources have been reviewed for this report:

Filename / Source	Title / Description	Doc No. and Issue	Author
EAN189_EAZ_EGEL_OnCabCo_v22_171029am_27700.zip EAN192_PIER_Offshore_Infrastructure.zip Utilities.zip	Mapping shapefiles	Received 11/12/2017	Vattenfall
3318_Happisburgh Nov 17 - FINAL (2).pdf	East Anglia (North) Offshore Wind Farm Landfall Site Investigation / Report on 9 No boreholes and testing results from Happisburgh and Cart Gap locations	Report No 3318-R006-3 Date: November 2017	TerraConsult
appendix-4.1-coastal-erosion-study.pdf	Norfolk Vanguard Coastal Erosion Study	Reference: WATPB4476R001F0.1 Revision: 0.1/Final Date: 17 May 2017	Royal Haskoning DHV
NVOW-01-Prelim22-061117.pdf	Map of preliminary GPR survey results, Happisburgh	6/11/2017	Headland Archaeology
NVOW-01-Int-22_FS mark up 20171221.pdf	Interpretation of geophysical survey results	21/12/2017	Headland Archaeology
OS Explorer Maps 1:25,000	Accessed through online subscription	Accessed 5/1/2018	Ordnance Survey
Bing Aerial Mapping	Aerial mapping	Accessed 5/1/2018	Bing

Filename / Source	Title / Description	Doc No. and Issue	Author
BGS Geology of Britain Viewer	http://mapapps.bgs.ac.uk/geologyofbritain/home.html 1:50 000 mapping of superficial and bedrock	Accessed 5/1/2018	British Geological Survey
BGS Borehole Logs: TG32NE33 TG32NE34 TG32NE41 TG33SE12 TG33SE16 TG33SE28	Publicly available borehole logs.	Accessed 10/1/2018	British Geological Survey
Shoreline_management_plan Kelling-Lowestoft.pdf	Kelling to Lowestoft Ness Shoreline Management Plan	Final Report 3/1//2010 Adopted August 2012	AECOM Limited
NE Norfolk and N Suffolk coastal trends report 2013.pdf	Coastal Trends Report North East Norfolk and North Suffolk (Kelling Hard to Lowestoft Ness)	RP033/N/2013 June 2013	Environment Agency
20151001RA-FR01 HDD Feasibility Report for EAN - Rev01.docx	HDD Feasibility Report - Cable Landfalls for East Anglia North Tranche 1 (EAN), U.K.	20151001RA-FR01 26th February 2016	Riggall & Associates Ltd

Table 1. Reference Documents reviewed for the Study. Additional references are listed in Section 16.

In addition to these documents a number of other resources have been accessed in compiling the report and these are listed in the References, Section 16.

For this study Vattenfall have stated that the assumed duct size is 500mm OD SDR11 HDPE.

1.4. Quality of Information

The available mapping information, both onshore and offshore, is at a scale suitable for this study but unsuitable for preliminary design stages or later. Lidar data or topographical surveys will be required for the chosen land and beach sites. A bathymetric survey will be required for the near shore and offshore areas.

The quality of geological information is reasonable for this level of study but further information is required for preliminary design stages and later. The available BGS borehole data is generally of low quality due to the majority of boreholes being for drilled water bores. The logs give very brief and general terms for the strata encountered but they are of significant depth and provide information on the depth to the boundary between the Crag and the Chalk.

The nearest geotechnical borehole log on the BGS website, TG32NE34, is located 500m east-southeast between the site and Cart Gap. Bored to 23m depth in 1984 for planning of the sea defences the geology correlates with the nearby boreholes completed for this project, however the SPT values in TG32NE34 are significantly higher than those in the project boreholes. The source of the disparity is difficult to determine, however the presence of “blowing sand” (see Section 4.2.3) can artificially lower or inflate SPT values depending on the technique used to manage it.

The geotechnical bores and testing undertaken for the project, provided in the TerraConsult report, provide good quality data for initial planning of the project. Field testing included SPT tests, variable head permeability tests and groundwater and ground gas monitoring. Laboratory testing included Index Property Testing, Particle Size Distribution, Consolidation tests, chemical testing, and water sample testing.

The documents related to Coastal Erosion are of high quality.

2. LOCATION OF SITE

The Happisburgh site is located 21km east-south-east of Cromer on the Norfolk Coast. The general location of the site is shown in Figure 1. The site is located midway between Happisburgh and Cart Gap. Indicative HDD alignments for the site are shown in Appendix A. The Ordnance Survey grid reference for the site is TG388303.

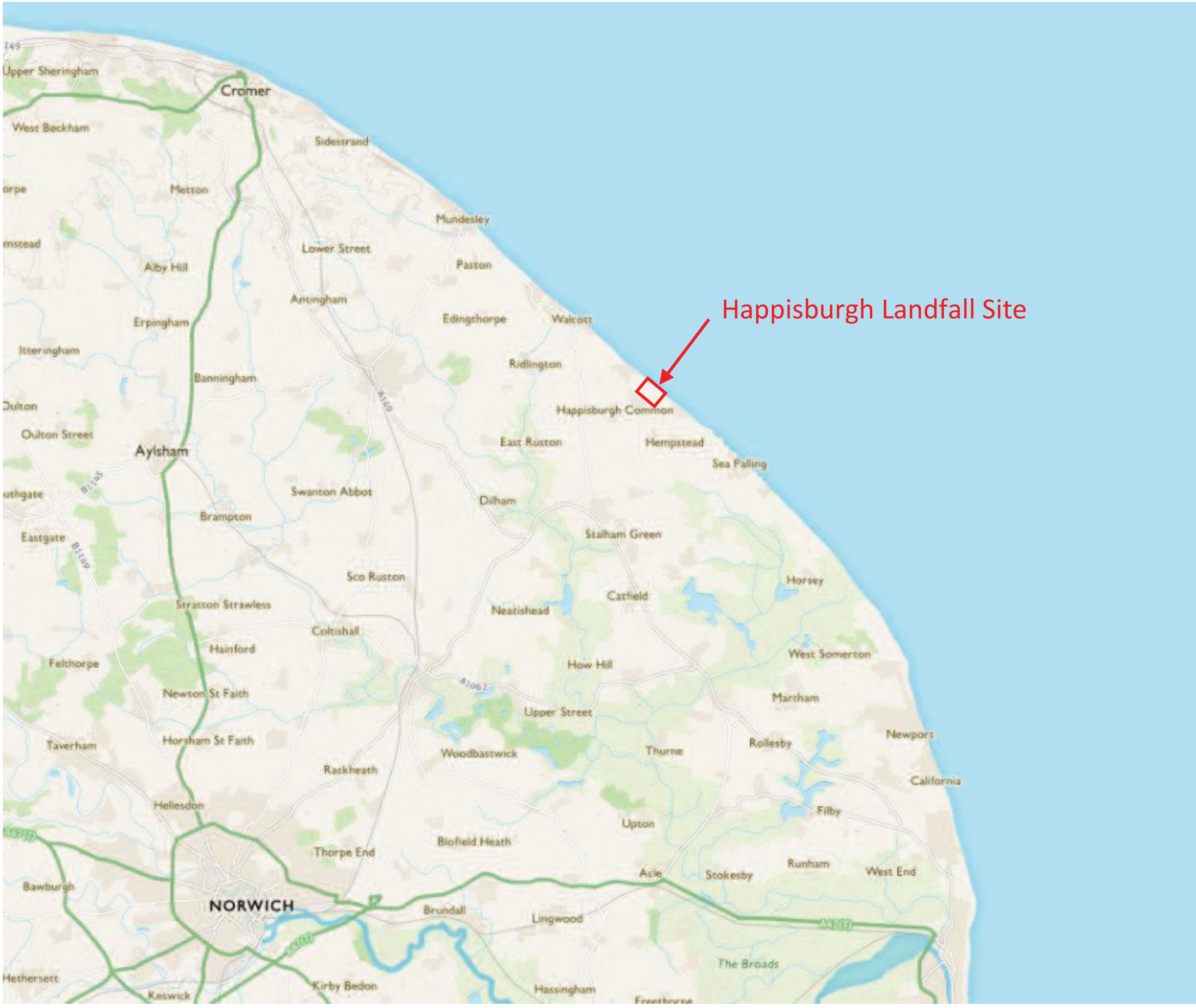


Figure 1. General Location of Happisburgh HDD Landfall Site.

The conceptual HDD alignments are drilled perpendicular to the coastline with the entry points set approximately 120m inland from the exiting coastline in order to provide protection for the cables against future coastal erosion.

3. TOPOGRAPHY AND BATHYMETRY

3.1. Topography

The topography of the coastline has an impact on the feasibility of a HDD. Ideally the entry elevation should be as close to sea level as possible to minimise the length of HDD borehole unsupported by drilling fluid. A secondary advantage is a reduction in the risk of drilling fluid “breakout” or “frac-out” (loss of drilling fluid to the surface). The entry elevation should, however be above the level of any potential coastal flooding.

During pilot hole drilling the entire borehole should be full of drilling fluid. The drilling fluid serves a number of purposes but two of the most important are removing the drill cuttings from the borehole and supporting the walls and roof of the drilled borehole.

When the drill exits on the seabed the drilling fluid will equilibrate to the sea level. The elevation at the conceptual HDD entry site at Happisburgh varies between approximately 6m ODN and 12m ODN. The length of unsupported borehole (after sea exit) is likely to be in the order of 23-46m and can potentially be mitigated by installation of temporary steel casing. However, given the density of the glacigenic sands that form the dry section of hole, casing is probably not required.

3.2. Bathymetry and Exit position

This report assumes bathymetry based on navigational charts. These charts are not of a high accuracy, particularly in areas such as the Norfolk coast where seafloor sediments are highly mobile and coastal erosion is occurring. For further design of HDD’s a marine survey of the area is required which should include bathymetry, sub-bottom profiling, and sampling and charting of seafloor sediments.

For this study it has been assumed that the HDD’s will exit either close to the LAT, the **Short HDD Option**, or at approximately -5.5 to -6.5m LAT, the **Long HDD Option**. The -5.0 LAT depth appears to be a point at which there might be a reduction in sediment transport, the seafloor slope is less steep from this point according to the charts.

The drawings in Appendix A also give indicative positions for 1000m length HDD’s exiting at approximately -9.5m LAT, because this length would considerably increase the number of cable vessels that could be used without needing a cable float in.

The final choice of exit point will be decided by factors such as the bottom profile, sediment depth, sediment grain size, projections for scouring or accretion on the sea floor, and the suitability for cable laying vessels. Assessment of these parameters will require marine surveys, therefore the exit points provided in this study should be taken as a starting point for further evaluation.

3.3. Depth of Cover of HDD

For the conceptual designs in this report a minimum depth of cover beneath the intertidal and marine sections of the HDD has been assumed as 14m with the design aiming to maintain 14-15m of cover in these areas. This is seen as a conservative depth based on previous projects.

The depth of cover will impact on thermal conductivity and therefore cable rating. Any further HDD design will need to balance the needs of maintaining sufficient cover to prevent drilling fluid breakout against minimising depth to improve cable rating.

3.4. Elevation Datum

Water depths on the Admiralty Chart are given in Chart Datum; the depth in metres below the Lowest Astronomical Tide (LAT) in a locality. LAT is approximately the lowest level due to astronomical effects and excluding meteorological effects.

All land elevations on Ordnance Survey mapping are given relative to Ordnance Datum measured at Newlyn (ODN).

The elevation of LAT measured in ODN varies around the coastline. For the purpose of this study it is assumed that at Happisburgh, LAT = -2.20mODN

For any final HDD designs at a chosen location the prior bathymetric survey should supply data relative to ODN in order to ensure there are no errors in construction.

3.5. Tidal Range

The tidal ranges for the study area is given below and is based on values for Walcott, 3.5km to the northwest. The value indicates astronomical tides, higher values can occur due to meteorological events.

Happisburgh – maximum tidal range 4.38m

4. GEOTECHNICAL

4.1. Geology Overview

The East Anglia coastline is formed by Holocene Alluvium (beach deposits, windblown sand, and peat) overlying a succession of glacial and fluvial derived deposit (tills, glaciofluvial sands, sands and gravels). Beneath these are Crag deposits (gravels, sands, silts and clays) that were deposited in estuarine or shallow marine conditions.

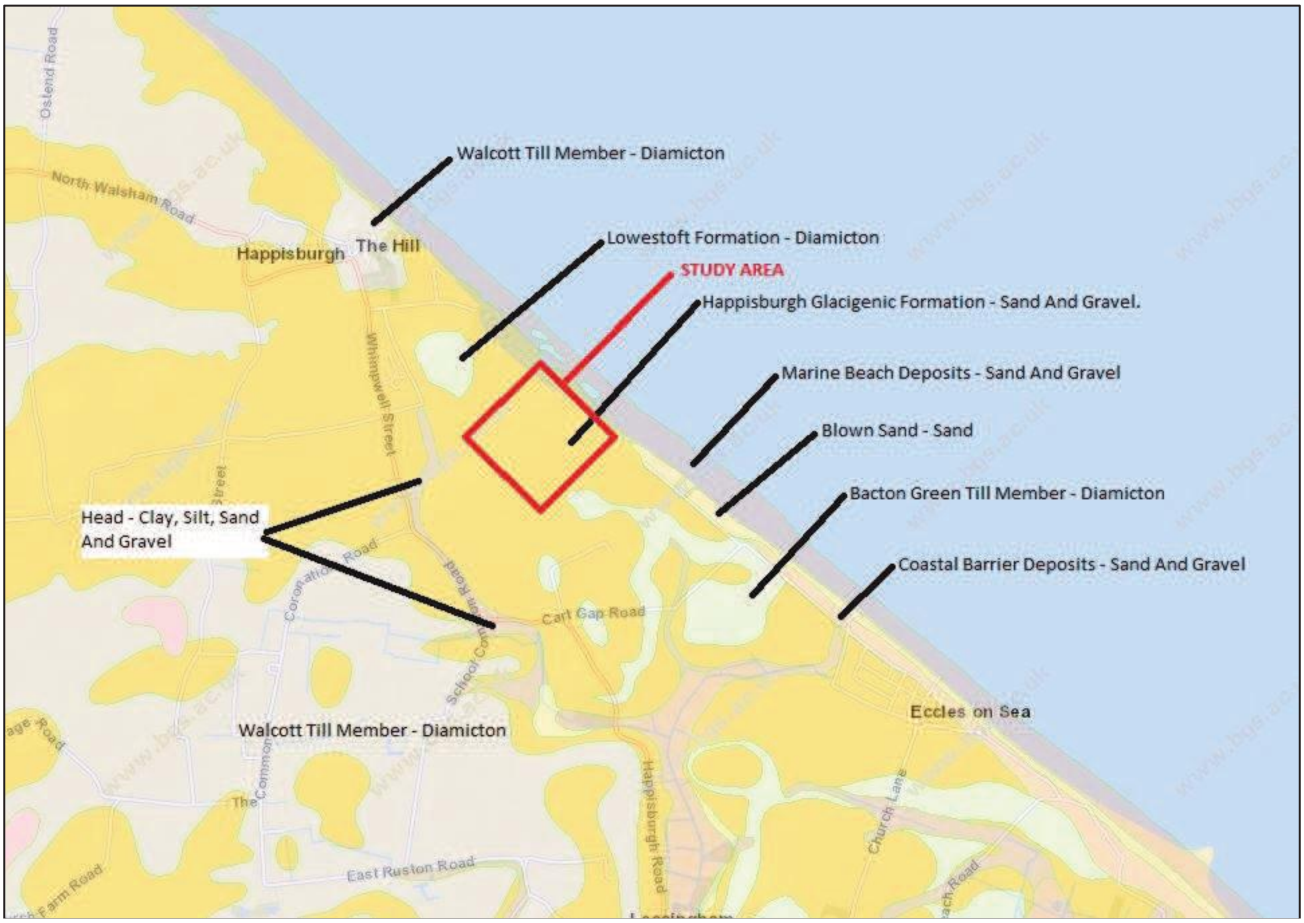


Figure 2. Annotated overview of superficial deposits at Happisburgh from BGS 1:50,000 mapping. Contains British Geological Survey materials © NERC 2018

At Happisburgh the Holocene Alluvium is only present in any thickness as beach deposits on the beach. The geology exposed in the coastal cliffs are fluvial and glacial deposits shown on BGS mapping as Happisburgh Glacigenic Formation, although in places there are thin outcrops of what would be termed Head deposits overlying the Formation. The Head deposits are remobilised sediments derived from the underlying Happisburgh Formation and similar in composition.

The outcrops in the cliffs at the north-western end of the site are predominantly silty SAND overlying sandy gravelly CLAY. The composition of the gravel includes chalk and flint and there are rare cobbles present. The cliff outcrops at the south-eastern end of the site are silty sandy CLAY with occasional cobbles of angular flint overlying fine yellow sand.

In the southern and middle part of the site there is a 140m width basin structure that could be caused by collapsed voids in the underlying chalk. The subsidence area is evident on the surface of the fields from topographical changes and at the time of the site visit its north-western margin was visible in the cliffs. The sediments within the structure have settled approximately 5-7m based on the exposures in the cliff. Further evaluation of the structure is given in Section 4.3.

Based on information from surrounding boreholes the Crag deposits are below sea level. Underlying the Crag is Chalk with the upper surface being at approximately-37m ODN.

A summary of the general geology at Happisburgh is given in Table 2 below.

GENERAL STRATIGRAPHY AT THE HAPPISBURGH SITE		
UNIT	**DESCRIPTION**	**THICKNESS**
Holocene Alluvium:	Marine Beach deposits (Sand and Gravel, significant thicknesses only on the beach)	0 – 3m estimated
Happisburgh Glacigenic Formation	Medium dense silty SAND sometimes with gravel in the upper sections, tending more to firm to stiff slightly gravelly sandy CLAY in the lower sections. Superficial Deposits formed up to 3 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions	Up to 14m
Wroxham Crag Formation:	Predominantly light grey to grey silty SAND. The deposits are interpreted as estuarine and near-shore marine.	34-40m
Chalk	Chalk with flints. With discrete marl seams, nodular chalk, sponge-rich and flint seams throughout	>40m

Table 2. General stratigraphy of the Happisburgh Site.

4.2. Suitability of Ground Conditions for HDD

4.2.1 Holocene Alluvium

The sands and sands and gravels of the Holocene Alluvium are only expected to be encountered at the exit of the HDD, particularly if the exit is close to the shore. Provided they are not of significant depth (>4m) they are not expected to be problematic. Greater thicknesses might require excavation from the exit point in order to mitigate the risk of gravels being dragged into the HDD during duct installation.

4.2.2 Glacigenic Formation

The silty SAND exposed in the coastal cliffs tends to be fine grained with gravel content varying from none up to 20% in some layers. They are generally medium dense and stand near vertically in the eroded cliffs. This suggests that they should form a stable borehole when supported by drilling fluid. However, the sections of the HDD's above sea level will be unsupported by drilling fluid once the HDD exits on the seabed and are potentially susceptible to localised collapse.

To mitigate against collapse, installation of temporary casing for the initial 30 – 50m of the HDD might be considered if collapse proves to be problematic during the drilling. However, provided the standard procedure of pulling a reamer in front of the duct during installation is followed there is a low risk of any collapses being problematic during installation.

Collapse within the initial 30-40m of the HDD could potentially migrate to the surface, causing a topographic depression, and the impact of this occurring should be assessed against the impacts to agriculture and archaeology along these sections of the HDD alignment.

The lower sections of the Happisburgh Glacigenic Formation are dominated by sandy gravelly CLAY, with flint being a component of the gravels and occasional cobbles. Flint can cause greater than normal wear on downhole equipment and possibly the drilling fluid recycling equipment. It might also require additional time to physically remove from the borehole but both wear and hole cleaning can be factored into schedule and price by the HDD contractor. Given the quantity of flint observed in the beach outcrops and the limited distance to be drilled through these units, the flint is only expected to cause minor additional wear during the HDD's.

Figure 3. Happisburgh Glacigenic deposits exposed in the cliffs at the north-western end of the site. The cliffs are formed in mostly silty SAND, the base of the cliffs and foreground is slightly sandy slightly gravelly CLAY.

4.2.3 Wroxham Crag

The Wroxham Crag is typically comprised of sands interbedded with lesser amounts of gravels, silts and clays. The sediments are usually dense and well graded (i.e. they contain a range of grain sizes). Figure 4 illustrates some typical coarser grained layers within the Crag from another Norfolk location. The TerraConsult boreholes drilled for the project only extended into the upper levels of the Crag and encountered fine to coarse SAND with rare gravel. The BGS boreholes suggest that with depth there is an increase in the proportion of shell and there are expected to be gravelly layers within the units. The grain size in the Crag appears to generally coarsen with depth.

Towards the lower levels of the Crag the percentage of flint in the sediments is expected to increase, however the HDD is unlikely to be drilling at depth within the Crag and excessive equipment wear caused by flints is not expected.

A potential risk within the Crag is the possibility of instability caused by blowing sands, also termed running sand and live sand. Some of the TerraConsult boreholes and the BGS boreholes note the presence of blowing sand and it is mentioned by Ander *et Al* (2006) in their regional analysis of the Crag.

Blowing sands describes where generally fine-grained sands are transported into the borehole because the fluid in the sand layer is at a higher pressure than the fluid in the borehole. In cable percussion ground investigation drilling this process can be magnified by the plunging effect of the drilling and sampling tool creating a reduced pressure as it is lifted from the hole. In HDD drilling running sands are normally contained in situ by the high viscosity and pressure of the drilling fluid.

The exception where HDD can have difficulty in containing running sands is where running sands are within artesian aquifers. Artesian aquifers are where the groundwater pressure within the strata causes the groundwater to flow to the surface of its own accord. Artesian pressures are not noted in any of the boreholes examined in this study and they are not expected given the design elevations for the HDD's. The noted occurrences of blowing sands in the TerraConsult boreholes are not accompanied by water strikes. Blowing sands are not expected to be problematic for the HDD because drilling fluid pressure typically counters any groundwater pressures that might contribute to the cause of blowing sands.

Based on the surrounding borehole logs the Crag should be a stable formation in which to drill a HDD. Drilling fluid should be of a high viscosity suitable for drilling in sands, and during reaming barrel reamers are expected to be more suited than fly cutters in order to compact and stabilise the borehole walls.

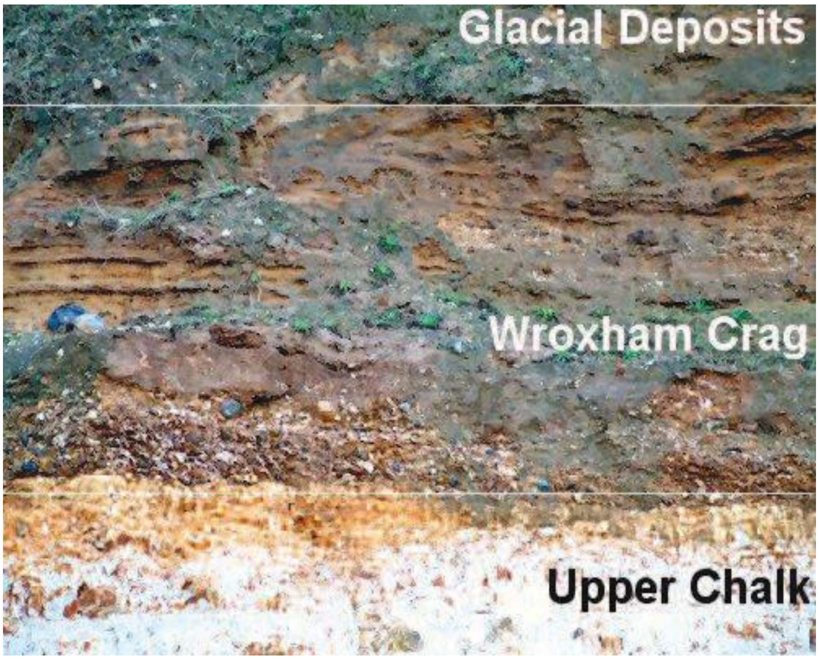


Figure 4. Cliff exposure from Weybourne, Norfolk showing Crag deposits. Photograph from http://www.weybourne.ukfossils.co.uk/Weybourne-Fossils-Geology/geology-guide.htm.

4.2.4 Upper Chalk

The chalk is not expected to be drilled along the HDD routes based on the onshore borehole information. The mapping of the Cromer Shoal Chalk Beds Marine Conservation Zone indicates chalk beds outcropping on the seabed 2km northwest of the site but there is no indication of chalk in the area directly offshore from the site. There is a chance that it is present at shallower depth beneath the seafloor, but this is assessed as a low chance given that the chalk is at -37m ODN in the onshore area.

The Upper Chalk has been drilled by HDD on other projects within the UK. It is normally good ground for HDD drilling, although there is the potential for losses of drilling fluid into permeable zones and localised chert or flint beds can increase equipment wear. Rock strength is likely to be in the order of 10-15 MPa requiring tri cone roller bits rather than jetting assemblies to drill. There is the possibility of soft weathered areas (putty chalk) occurring, particularly at the top of the chalk.

4.3. Ground Subsidence Structure

A potential ground subsidence structure has been identified at the site based on topographical information and the geophysical survey undertaken for archaeological assessment. The feature is assumed to be caused by settlement above a collapsed void in the underlying chalk. The interpreted dimensions of the feature (Figure 5) are 300m along the long axis (070° strike) and 140m along the short axis (160° strike), although the feature might extend further eastward than interpreted.

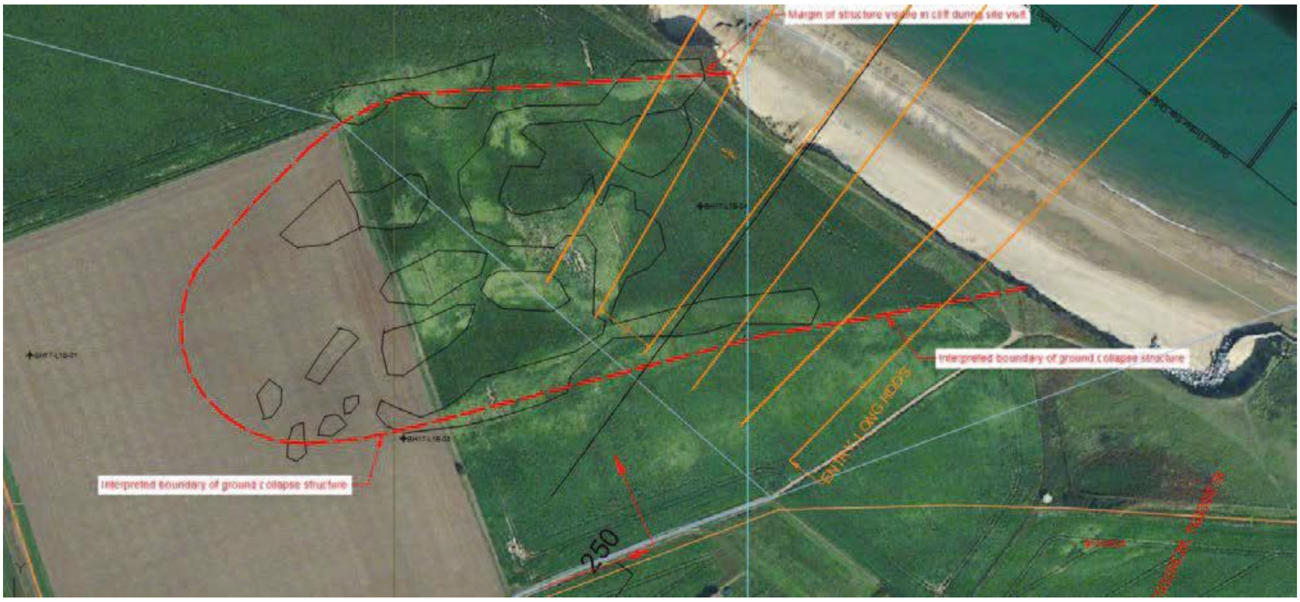


Figure 5. Estimated margin of ground subsidence structure indicated by red dashed line. Black lines indicate topographical variations interpreted from 1946 aerial photograph. The orange lines indicate potential routes for HVAC cable HDD's.

During the site visit the north-western margin was visible in the cliffs where the interbedded Clay and sand layers could be seen to be gently folded. The south-eastern side had settled by approximately 5-7m, however the depth of settlement is likely to be greater in the centre of the basin. Measurements on the monocline forming the edge of the trough showed that at that location it inclined at 30° towards the south (160°). This direction correlates with the outline of the feature interpreted from aerial photography and observation of the terrain made during the site visit.

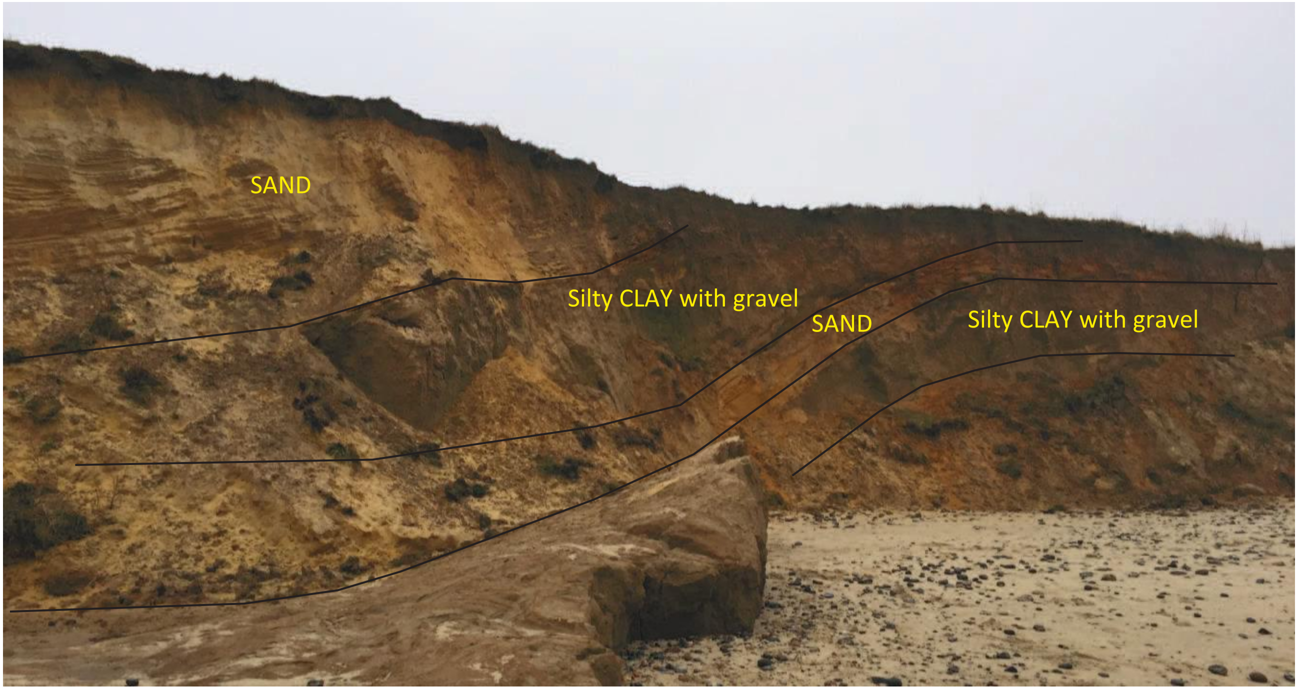


Figure 6. Photograph showing the north-western margin of the subsidence basin. The lower left of the photograph shows the lower silty CLAY with gravel layer within the basin approaching a near horizontal attitude. The right of the photograph shows the horizontal strata in the unaffected zone. The centre of the photograph shows inclined strata along the margin of the subsidence area.

The inclined strata along the margin of the subsidence zone showed no sign of faulting or fracturing indicating that the source of the ground collapse is at considerable depth and that subsidence at this level either occurred slowly, or occurred when there was a reasonable thickness of overlying sediments constraining the unit. The stratification and cross bedding in the lower SAND unit shown in Figure 6 indicates that it was deposited in a near horizontal orientation and that it has become inclined subsequently due to the subsidence.

Based on the evidence seen in the cliffs the subsidence event appears to be geologically recent; some time after the glacial retreat 12,000 years ago. It is thought to have most likely to have developed between glacial retreat and 5,000 years ago when sea levels rose to near their present levels. During this time the site would be well above sea level and there would have been a greater volume of groundwater flow through the chalk than at present. Dissolution of the chalk might then create a cave with ground above progressively collapsing into it with the broad settlement basin at surface resulting.

Based on aerial photographs there is no evidence to suggest that the subsidence has occurred in the last 70 years, or that the margins of the feature have been extended over the last 70 years. In Figure 7 two aerial photographs are shown side by side. On the 1946 photograph the outlines of drier ground have been drawn which indicate changes in topography from the higher ground to the hollows. These outlines superimposed on the 2012 photograph match the drier, and therefore higher ground well. This indicates that any subsidence occurred prior to 1946 and that there is no indication that the area has enlarged since 1946.

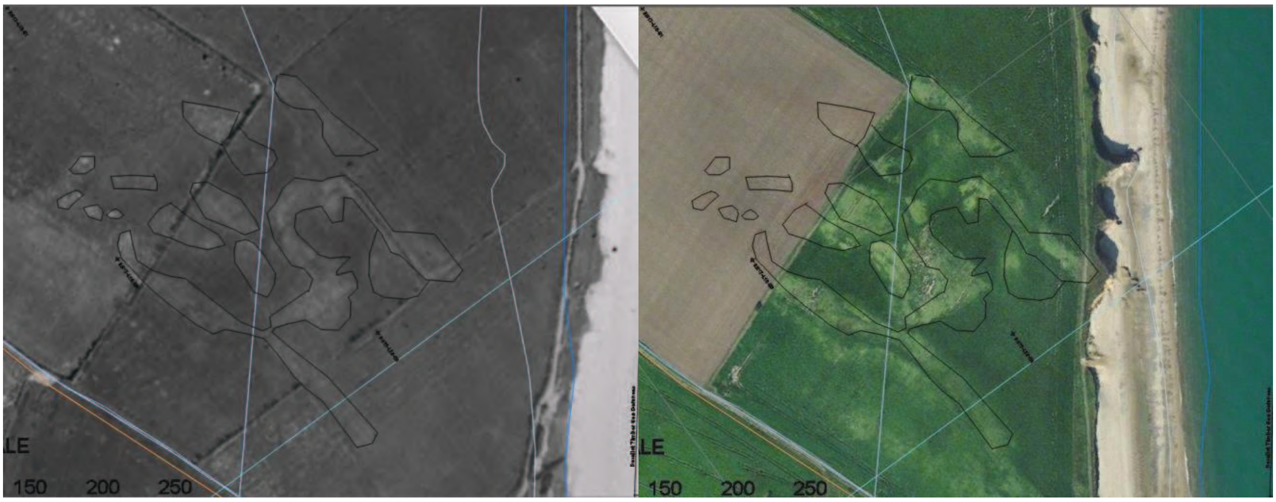


Figure 7. Aerial photographs of the site in 1946, left, and 2012, right with outlines of drier ground from 1945 (black lines) superimposed on the 2012 photograph showing no obvious change.

Circumstantial evidence that the topography has been in its present form for a considerable time is also provided by the interpreted trace of a former road or track through the area. The former track or road deviates to keep on level ground and avoid two marked hollows. The track is traceable for 1km through the study area. It is not present on the 1885 Ordnance Survey map, suggesting no significant change in topography for at least 130 years.

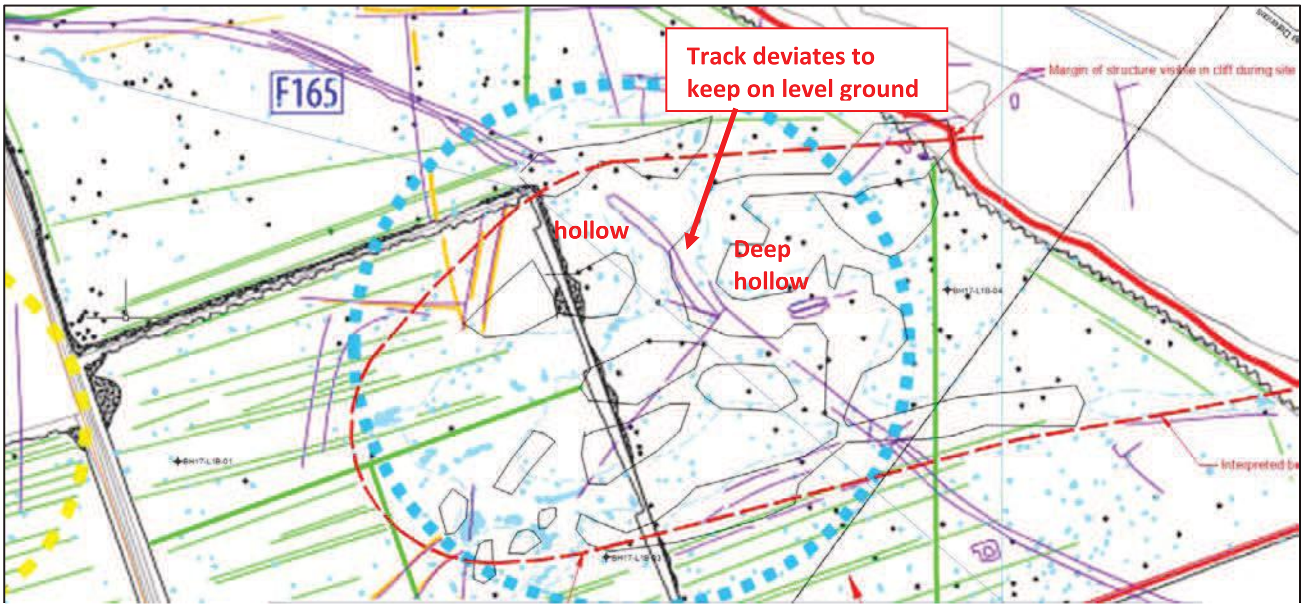


Figure 8. Preliminary archaeological interpretation of features in the area of the subsidence zone. The possible track feature in purple deviates to avoid surface hollows as it traverses the subsidence zone. The road pre-dates the 1885 Ordnance Survey mapping.

Research of collapses in chalk ground in the Norfolk area for this report found only examples of cases where the subsidence was caused by collapse in former chalk mines. There is no evidence of chalk mining extending beneath the HDD landfall area, the chalk is at depth and is unlikely to have been mined when near surface resources were readily available in places like Norwich.

Additionally, the volumes of water drawn from boreholes in the chalk in the area indicate that mining would have required substantial dewatering and is highly unlikely.

4.4. Hydrogeology

The Cretaceous Chalk forms the most important aquifer in England, whilst the Crag is a locally important resource over its outcrop area in East Anglia. The study area is not within a Groundwater Source Protection Zone according to the Environment Agency interactive mapping. The mapping also shows that none of the sites is within a Drinking Water or Groundwater Safeguard Zone.

The Environment Agency interactive mapping of Water Abstraction Licences indicates there is only one groundwater abstraction site within 2.0km of the site, and four within 3.0km. The sites are all medium size abstraction for agricultural use.

BGS Groundwater Vulnerability Mapping indicates that the bedrock (the chalk) beneath the site is a Principal Aquifer and the superficial deposits are a Secondary-A Aquifer. The groundwater vulnerability mapping indicates a Medium-High Vulnerability. Therefore, despite the significant distance to abstraction points, any ground investigations and design for a final HDD will need to consider and assess the risk to groundwater from the works.

Given the location of the HDD's on the low lying coastal margin it is unlikely that groundwater flow will be south-westward (inland) leading to contamination of abstraction points by drilling fluid. Additionally, drilling fluid losses into aquifers would only occur if the HDD drilled directly into a high flow aquifer because the drilling fluid is designed to seal the annulus of the borehole by forming a filter cake around the wall of the bore.

Falling head permeability testing was undertaken in three of the project boreholes in ground varying from silty slightly gravelly SAND to silty slightly sandy CLAY. The results of the test indicate permeability typical of silt and glacial till, generally low permeability for superficial deposits, and provide confidence that loss of drilling fluids due to high permeability is unlikely during HDD drilling. None of the borehole logs show groundwater under high flow (other than in the chalk) or artesian pressure. Any groundwater encountered in the HDD's will therefore be sealed by drilling fluid.

5. ENVIRONMENTAL

The main environmental risks affecting the site are the impact of the HDD on the natural environment (marine, intertidal and terrestrial), and the impact of coastal erosion on the cable installation.

On other sections of this coastline the risk of flooding to the HDD works during construction is a consideration, but at the Happisburgh Site the entry elevations and work sites are all several metres above the 1953 tidal surge level of 3.75m, mitigating this risk.

5.1. Designated Areas

A check on the UK government's Magic Map Application revealed there are no existing designations for the site and the marine section of the HDD route. However, the marine section of the HDD route is shown as a Potential Special Protection Area (SPA) and candidate Special Area of Conservation (SAC).

Just to the north of the site is the southern boundary of the Cromer Shoal Chalk Beds Marine Conservation Zone (MCZ) that was designated in January 2016. The Happisburgh site is outside the MCZ with the closest of the Conceptual HVAC HDD cable routes being 180m from its border. The HDD construction is not expected to have any direct impact on the MCZ.

5.2. Coastal Erosion

The section of Norfolk coastline containing the site is subject to coastal erosion. The process has been occurring along East Anglia for centuries and will continue to do so, in part accelerated by sea level rise.

A Shoreline Management Plan (SMP) has been developed for Kelling to Lowestoft Ness that covers the Happisburgh site. The SMP indicates coastal management policy for the Short (to 2025), Medium (to 2055) and Long term (to 2105) and arrives at estimated coastal erosion for 2025, 2055, and 2105, reproduced in Figure 9 below.

Royal Haskoning have produced a coastal erosion report for the site and found that the SMP predictions could be conservative because they assume that existing sea defences north of the site at Happisburgh, and south of the site at Cart Gap, are maintained at their current level.

Royal Haskoning suggest a "reasonably conservative estimate of future cliff erosion at Happisburgh is 25 metres by 3035 and 50 metres by 2065. This is based on the assumption that the 'bay' at Happisburgh has reached a dynamic equilibrium."

In determining the position of the HDD entry points for the conceptual design, this report has taken a conservative approach and ensured that the installed cables will be below the level of the 2055 beach if the SMP predictions are correct. In places this represents an additional 35m of drilling compared to using the Royal Haskoning 50m coastal retreat position. The additional drilling represents considerable added security for perhaps an additional 1.5% - 3.0% HDD construction costs for the 700m length HDD option.

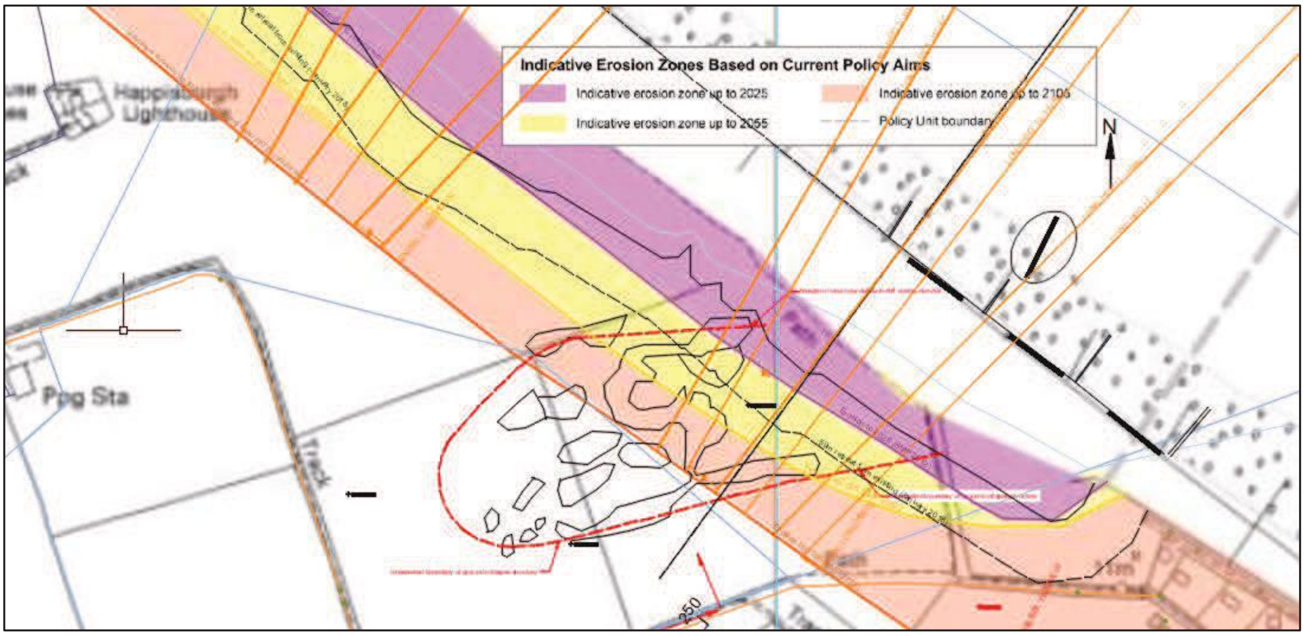


Figure 9. Extract from the Kelling to Lowestoft Ness SMP with conceptual HDD alignments and site location. An additional black dashed line indicates 50m setback from the existing (2017) coastline, a figure suggested in the Royal Haskoning Coastal Erosion Report.

5.3. Coastal Defences

To combat the effects of coastal erosion on property and resources much of the Norfolk coastline has been protected with coastal defences. The coastline in front of the Happisburgh site has previously been protected by timber breastwork and projecting timber groynes. The south-eastern section of these defences is still partly in place in front of the site. It is not known whether the substructure of the destroyed defences is still in place and what depth they extended to.

To the south east of the site steel sheet piles are present along the toe of the timber breastwork. It is not known whether steel sheet piles were also used on the section in front of the site. During the site visit, despite it being low tide, the base of the abandoned sea wall was still below the water level.

If a short HDD, exiting in the intertidal area, is to be considered, further investigation will be required into what sea defences remain, their composition, and their depth.

For the long HDD's it is probably sufficient to investigate the depth of penetration of the defences, either from construction records or site investigations, in order to ensure that any design is below the level of their foundations.

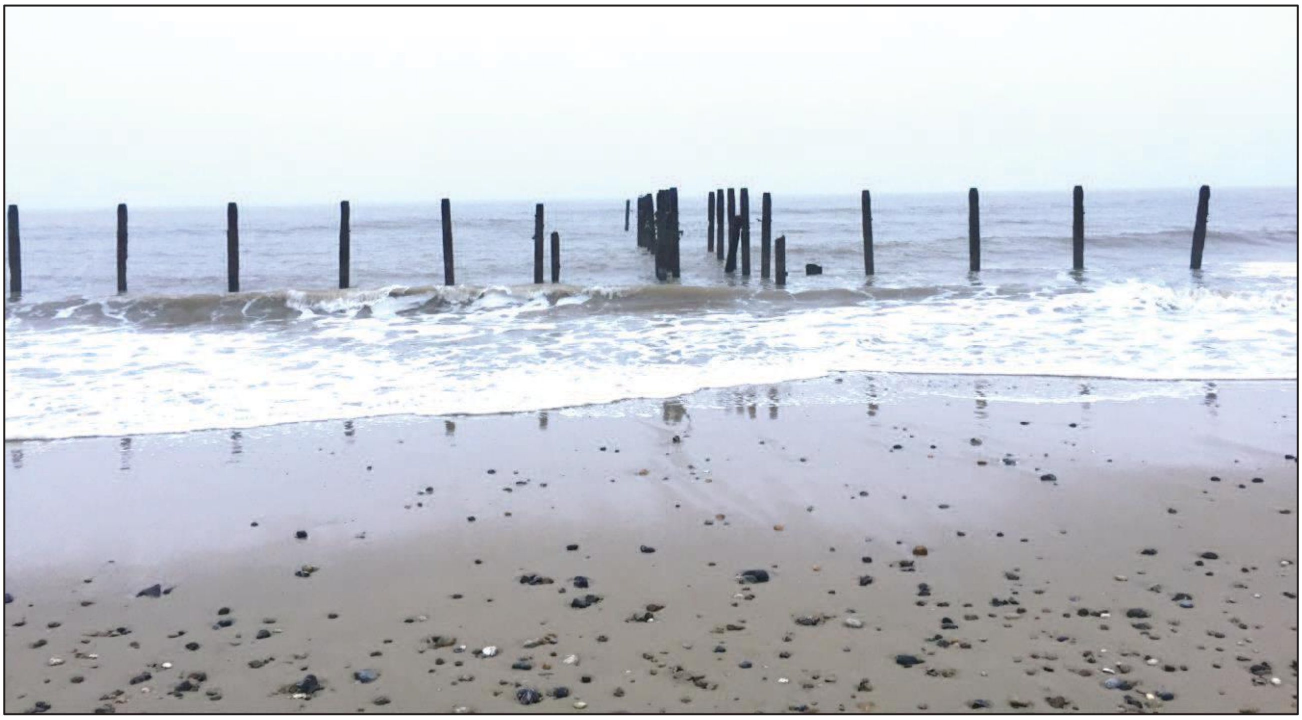


Figure 10. Remains of timber sea defences in the south-eastern half of the beach. Note that further to the south-east there are steel sheet piles at ground level along the sea wall. It is not known if these were used along the sections in front of the site.

5.4. Flooding

The Happisburgh site is highly unlikely to be subjected to flooding. The elevation of the site is approximately 6m to 11m ODN. There are no rivers adjacent to the site and there is no significant catchment area that would lead to surface runoff flooding the site. Tidal surge events within the last 100 years have been at lower elevations; the 1953 tidal surge affected land below +3.75m ODN and the 2013 event was at a lower elevation than the 1953 surge.

6. ANTHROPOGENIC FACTORS

There are a number of anthropogenic (mad made) factors to be considered for HDD working at the Happisburgh site.

The works will need to consider and mitigate the archaeological potential of the area; the immediate area has a rich history of archaeological finds.

The site is sufficiently removed from nearby permanent residences to allow mitigation of noise and lighting concerns, but consultation with nearby residents and stakeholders will be required in particular to best manage traffic movements for the works.

Land ownership of the sites has not been addressed in this report, but it is noted that there are only two key landowners for the conceptual HDD sites and potentially another two landowners for access roads to the site.

This stretch of coastline saw extensive defensive installations during World War II. A UXO desk study of the chosen site will be required to determine the risk of unexploded ordnance and determine the level of any detection required during ground investigations and construction.

6.1. Archaeology

The study area has a long archaeological history. The oldest (c. 850,000 years) hominin footprints outside of Africa were found 1km northwest of the site. The site itself, and coastal strip in front of the site, is identified by Norfolk Heritage Explorer (NHE) Mapping as having the following features and finds:

- Prehistoric flint artefacts
- Lower Palaeolithic lithic working and kill site, 'Happisburgh Site 1' (now submerged or eroded)
- Early Bronze Age axe head
- Bronze Age sword fragment
- Bronze Age barrow cemeteries and ring ditches
- Iron Age or Roman field systems
- Cropmarks of undated field systems, ditches, trackways, pits and possible grubenhauser
- Site of the Hunter, a post medieval wreck (1807)
- World War Two barbed wire obstructions and possible weapons pits
- World War Two pillboxes

Headland Archaeology are currently undertaking a study of the site. Overlaying the conceptual HDD sites on the preliminary interpretation of GPR results (Figure 11) indicates that the potential HDD sites are in areas relatively clear of lineaments or structures. The purple lines traversing the entry pits is a former road of unknown age; it predates the 1885 ordnance survey mapping. Individual HDD entry pits can be moved forward or backward several metres to avoid this, or other, archaeology if needed.

Archaeology at the site is only expected to be permanently affected by the HDD if it exists at the location of the entry pits or at the line of sheet piles used to anchor the drilling rig. The trenched onward cabling from the HDD's and the transition joint bays also have the potential to permanently disturb archaeology, but they have some flexibility to be positioned and routed through less sensitive areas.

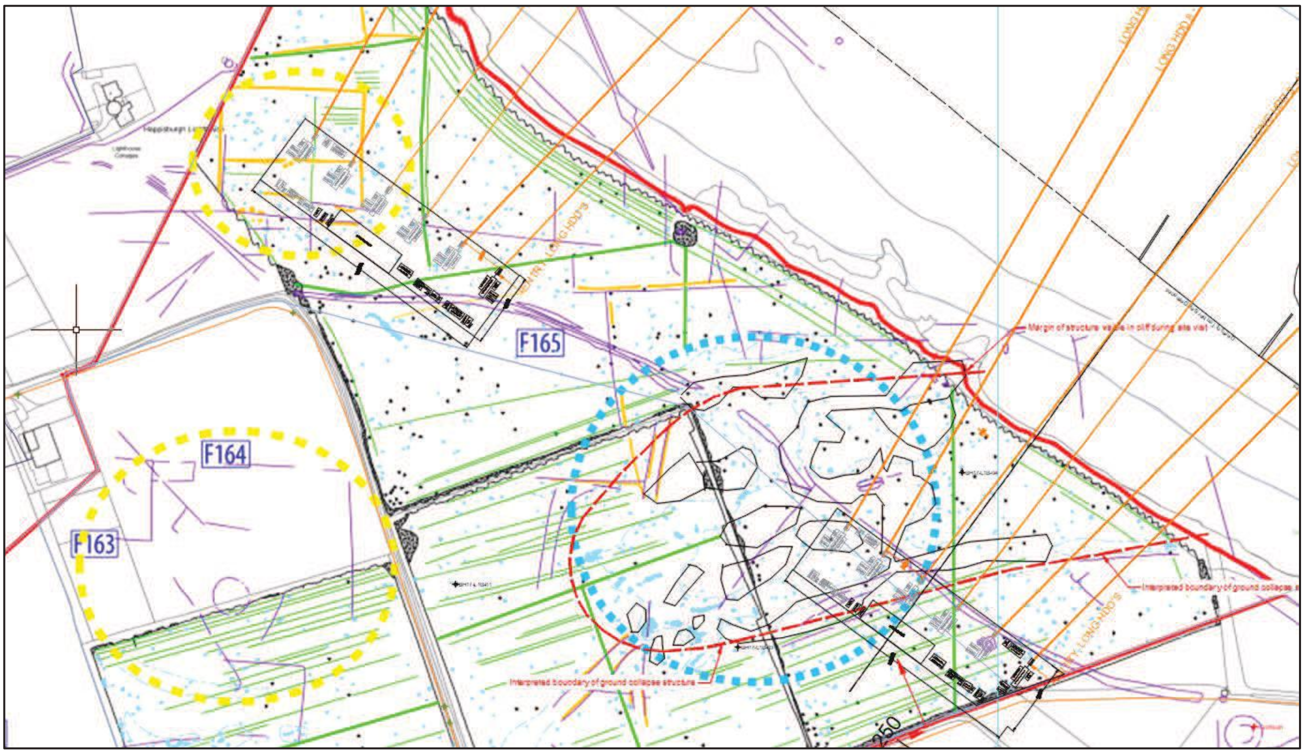


Figure 11. Conceptual HDD sites and drilling alignments for HVAC cables (orange lines) overlaid on a preliminary interpretation of GPR results.

The entry pit for each HDD is typically of dimensions 3m width x 4m length x 2.5m depth. The sheet pile anchor for each HDD is typically a 5m length by 0.25m width area with the long axis perpendicular to the drilling direction. The HDD entry points can potentially be moved within a 5m radius to avoid any sensitive finds. They might be scope to move within a 10m radius subject to there being no adverse effects on cable rating from proximity to other cables. As an example, the entry position for HVAC HDD11, the second orange line from the right in Figure 11, appears to be directly on the former foundations of a building. If required the HDD could be moved 10m northwest or southeast to avoid disturbing the area.

During site preparation the HDD site, and some of the access track, will be stripped of topsoil that will then be stockpiled around the perimeter of the site or track. During these earthworks it is probable that there will be an archaeological watching brief. If the site or access cannot avoid areas that have been identified by surveys to hold archaeological interest, they should be explored in trial trenches well in advance of the main works to avoid any undue delay to the works.

Archaeological finds at the exit positions, while possible, are less likely due to the intertidal or marine environment and the probability that the exit will be in marine sediments that are subject to migration. If finds do exist they are unlikely to survive or be recorded because of their environs. The impact of the exit point is also reduced to the diameter of the borehole, approximately 0.8m.

6.2. Noise

There are no set specific limits for construction site noise; however British Standard 5228 provides guidance on managing noise from construction. Example Method 2 in Annex E states noise levels generated by construction are deemed to be significant if pre-construction ambient noise is exceeded by 5dB or more subject to lower cut-off values of 65dB, 55dB and 45 dB $L_{Aeq, Period}$ from construction noise alone for the daytime, evening and night-time periods.

Using these lower cut-off limits (65dB, 55dB and 45 dB $L_{Aeq, Period}$) the distances from the site affected by greater levels of noise are 70m (daytime), 190m (evening), and 360m (night). These distances are based on modelling and monitoring results from maxi HDD projects in the UK plotted in Figure 12 below.

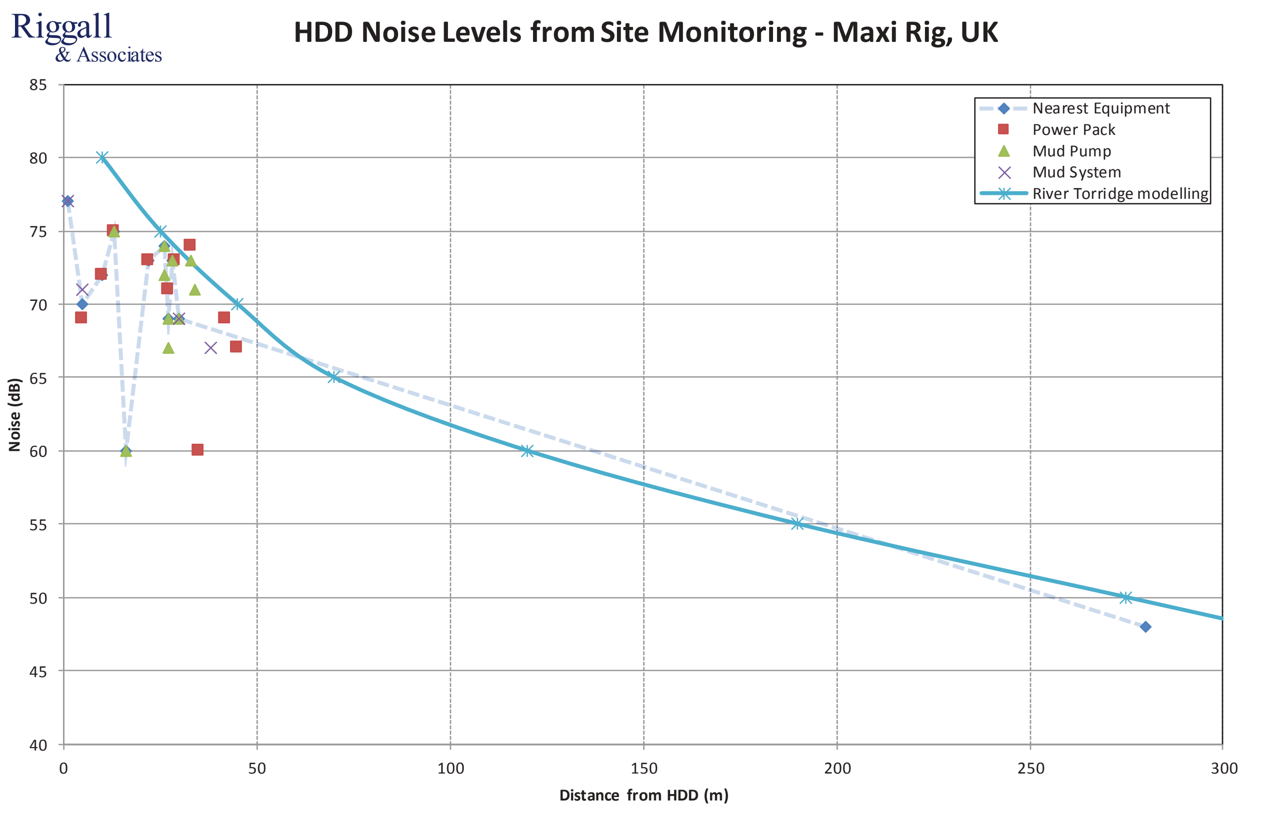


Figure 12. Modelled and monitored noise levels from several maxi rig projects in the UK.

For pullback (duct installations) 24-hour operations should be provisioned in case of any difficulties in the operation. Overnight working is unlikely to be required because installation should take less than a shift to complete for the long HDD option, but nevertheless it should be available.

The HVDC option will have no significant difficulties caused by noise because the working area is small and can be located at least 360m from the nearest potential (permanent) residence at the end of Doggett's Lane, allowing 24hr working.

The HVAC option will need some form of noise mitigation if extended periods of 24-hour working are planned. The four HDD's at the north-western end of the HVAC working area (HDD1 through to

HDD 4) are between 300m and 360m from the nearest residences; located on the corner of Lighthouse Lane to the west of the site. At this distance day and evening working will be acceptable, but night working will require mitigation measures to be put in place.

For noise mitigation attenuation fencing is commonly used and can be extremely effective when strategically placed. In urban areas with properties within 50m of the equipment sea containers are often used as noise screens. They can be stacked to increase the height but stability in high winds should be ensured through temporary works design, particularly in this exposed coastal location.

Figure 13. Noise attenuation panels on Heras Fencing on a recent UK project. The nearest neighbour was 100m from the panels. The work included allowance for 24hr working during duct installation.

Figure 14. Stacked shipping containers used for noise attenuation panels on a UK project. There were 4 residences within 50m of the site. The work included regular evening work as well as 24hr working during pipeline installation.

Consideration will also need to be given to residents living beside site access roads and routes, because the works will increase the volume of traffic and therefore noise. Unless it is essential, heavy vehicle movements to and from site during night time should be restricted.

Good community relations are invaluable in managing the impact of noise on the local community; regularly discussing the nature, timing and duration of the works with residents often resolves issues before they materialise.

6.3. Vibration

Vibration from the HDD is not an issue for this location. The drill itself can only be felt when it is less than 3m depth below surface and within a few metres of the drill line. The most vibration generated on a site is always when an excavator tracks around the site.

There have been studies of vibrations from HDD sites, an example of which is the Ground Vibration Monitoring Survey at the River Wye. The River Wye Vibration Monitoring equipment was positioned only 3m from the entry point. The level of vibration was well below DIN 4150 Maximum Vibration Level for the entire time and apart from thirteen readings the vibration was below the guidelines for sensitive structures.

6.4. Light

Light pollution is unlikely to be problematic for nearby residences. Careful planning of lighting, with particular attention to the height and orientation of any lighting towers will ensure that any residences with a direct view of the site will not be inconvenienced.

Consideration will need to be given to the planning of lighting due to the Happisburgh lighthouse. While shipping is unlikely to confuse the lighthouse and the site, the works will probably require a Notice to Mariners and consultation with the harbour authorities at Wells Harbour and Peel Ports Great Yarmouth.

6.5. Traffic & Access

6.5.1 Site Access

For this area of the coast traffic congestion is a significant problem over holiday periods. The level of traffic movements generated by the HDD works will not be significant relative to other traffic but there is a risk that they might be perceived as adding to local congestion. From the contractor's view, work during the summer holiday period is best avoided as any mobilisation, deliveries and crew travel will potentially be disrupted.

The most suitable route for site traffic from the A149 is via the B1159 and North Walsham Road, as shown in Figure 15 below. The B1159 is the designated route for all heavy vehicles to Bacton Gas Plant so is suitable for HDD traffic. North Walsham Road is dual lane, although there are sections where it is narrow and HGV drivers should be warned to take care. On the approach into Happisburgh there is a school; it would be sensible to schedule site deliveries to avoid school drop off and pick up times if possible.

For mobilisation of equipment to site it might be prudent to have traffic management (probably stop and go boards) on the right-hand bend in the centre of Happisburgh if it is thought that loads might need to cross the centre of the curve.

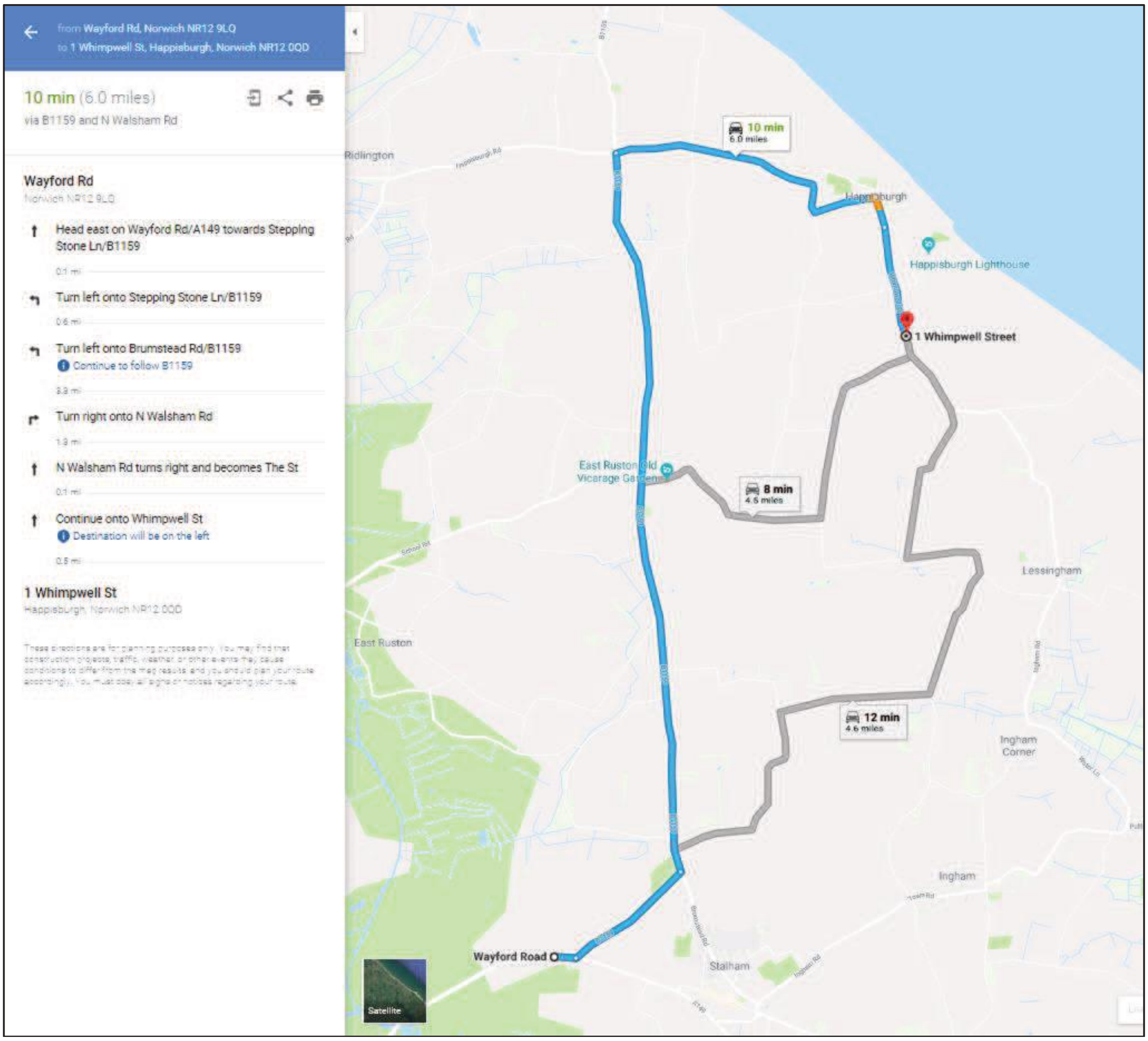


Figure 15. The most likely route for site traffic from A149.

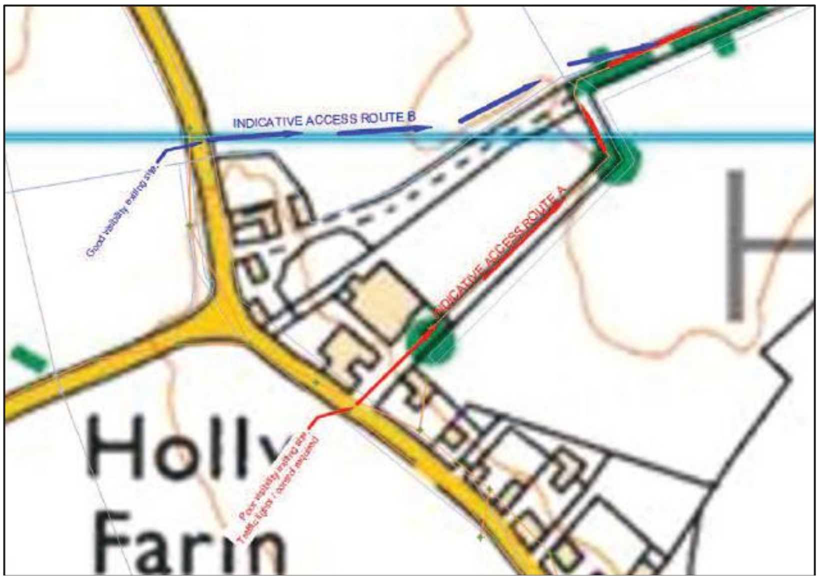


Figure 16. Potential access routes from Whimpwell Street.

From Whimpwell Street the access with the better visibility is shown as Route B (blue) on Figure 16. Route A, while existing and sufficiently wide, has very poor visibility and would require traffic lights to be in place for the duration of the works. It should be noted that Route A is a public footpath, so both routes A and B will need to make alternative provision for walkers during the work. Route B might have to be evaluated for archaeological impact beside Whimpwell Road, based on preliminary archaeological survey results.

Consideration has been given to using Lighthouse Lane, however it is single lane with a soft verge and insufficient turning room into it from Whimpwell Street. It is unsuitable for heavy traffic.

Another alternative considered was accessing from Barton Lane, south of the site. The advantages of this route are that traffic must slow for the right-angle bend on the main road and visibility is good in either direction. The disadvantages are it is a 4-way junction and turning into Barton Lane would require a widening of Barton Lane. Barton Lane itself is a single lane gravel track and will need some upgrading or repair and it will require 400m of temporary track along the edge of the field to get to site. Route B requires approximately 200m of temporary track, Route A requires none.

Typical traffic movements (return journeys per day) during the HDD works area as given in Table 3.

CONSTRUCTION PHASE	RETURN JOURNEYS PER DAY				Duration
	HGV	MGV	Light Vehicle	Other	
Groundworks	8	4	8		3 weeks (15 days)
HDD Mobilisation	10	2	10	1 No 300t Crane	2 days
HDD Works:	1	4	8		TBC
HDD Demobilisation	10	2	10	1 No 300t Crane	2 days
Site Reinstatement	8	4	8		4 weeks (20 days)
Note:	MGV taken to include Luton vans, Tractor & Bowser				

Table 3. Indicative site vehicle movements for HDD works.

6.5.2 Beach Access

For the case of short length HDD's exiting in the intertidal area, beach access would most likely be via a temporary ramp constructed from the southern end of the bay. At this location the cliffs are relatively low, 3m to 4m in height. An example of such a ramp can be seen on aerial photographs taken during construction of the protective rock wall at the south-eastern end of the beach (Figure 17). The ramp has since eroded away and a new ramp would need to be constructed for any works. The ramp would only need to be suitable for tracked vehicles, although access suitable for a tractor and bowser would improve productivity.

An alternative route is to use the existing beach access at Cart Gap, 900m to the south. There are gaps in the timber groynes that would allow passage along the beach, however access would be restricted to low and mid tide.

During the works the section of beach will probably need to be off limits to the public for public safety. Works will also need to ensure that there is a safe egress from the beach work site at high tide.

The works during HDD exit in the intertidal zone are typically only of 3 to 5 days duration for each HDD. Works for clearance of the sea defences along the route and cable pull in are likely to require 2 days to 4 days per HDD depending on the construction method used. These estimates indicate a total of 20 to 36 days of working on the beach for the short HVDC option and 60 to 108 days for the short HVAC option.

For the case of long HDD's no beach access is required.

Figure 17. Access ramp (top right) created for construction of rock wall at south-eastern end of the beach (bottom left) in approximately 2010. Bing Maps.

6.5.3 Sea Defences

The option of a short length HDD will need to assess the location and depth of any remaining sea defences. The HDD itself will exit before the remnant defences, however the onward cabling will route through them. There are two possible construction techniques to bury the cable through the sea defences area.

The first method is to excavate and remove or clear the sea defences to a suitable depth along the route prior to cable arrival. When the cable ship arrives a cable plough can then install from close to the HDD exit.

The alternative method is to use steel sheet piles in a corridor through the sea defence and excavate between them to the required level. A cable plough then installs from the seaward end of the sheet piled zone.

6.5.4 Public Footpaths

There is a public footpath along the probable site access from Holly Farm on Whimpwell Road to the beach and the England Coastal Path runs along the top of the coastal cliffs. HDD works are unlikely to disrupt the England Coastal Path; beach access for the option of short HDD's would cross the path but traffic would be intermittent and there would be no need to close the path.

The Holly Farm to beach path will need a temporary diversion, probably alongside the access in the fields on the south-eastern side. The path was well used during the site visit, a cold overcast January day, so will be used even more at warmer times of the year.

6.6. Unexploded Ordnance

Regional Unexploded Bomb county maps by Zetica were consulted but there is no designation for the area. Heritage mapping and Albone et al (2007), reveals that there were World War 2 coastal defences in the area including two 6-inch batteries approximately 300m north of the site that had to be replaced with a 4.7 Inch battery, 1.6km northwest of the site, due to cliff erosion. Other defences include a number of pill boxes, two of which still survive, and lines of barbed wire.

While the risk to HDD construction is likely to be low, prior to any ground investigations or HDD construction the site will require an initial UXO desk study to assess the risk and inform further requirements.

7. CONSTRUCTION LOGISTICS

7.1. Water Supply

The greatest rate of water usage on site will be during the forward reaming stages. An approximate figure for a water consumption over a 12-hour shift in fast drilling conditions is $40m^3$ (40,000 litres). This volume could easily be supplied from an external source using a tractor towing a medium sized bowser (11,000 litres). Similar projects have used on site water storage in addition to the drilling fluid system; $20m^3$ storage is typical to ensure drilling progress is not interrupted but some contractors allow for up to $80m^3$ storage to insure against interruption to supply.

The closest hydrant point is at the intersection of Coronation Road and Whimpwell Street; however, the hydrant is at a busy location and probably unsuitable for supplying town water to the HDD. Other potential sources of town water are from the supply running along Doggett's Lane, or from Lighthouse Lane. Connection to these supplies could use a temporary PE pipeline to transfer water directly to site, however Anglian water will need to determine whether the supply is suitable and volumes are acceptable.

Stop valves were observed on the site visit beside the potential access track to the site, indicating that there are permanent irrigation pipelines buried beside the track. Bore water from the chalk would most probably be suitable for drilling fluid supply and these are a possible source. The nearest bore has a licence to abstract up to $660m^3$ daily, so $40m^3$ daily should be possible.

The worst-case scenario would be supply from a remote source (town water or bore water) using road tankers ($30m^3$ capacity). This has been done on many large HDD projects in the past but has disadvantages in cost and additional road traffic.

7.2. Overhead Lines

There are no overhead lines affecting the site. There are BT overhead lines on the western side of Whimpwell Street which cross the road to supply residences but these do not obstruct normal traffic movements. HDD equipment will be transported to site on standard articulated vehicles and are not wide loads or high loads.

7.3. Buried Services

Information on the drawings supplied by Vattenfall indicate buried BT cables along the tracks just to the west and south of the proposed HDD sites. There also appear to be buried irrigation pipelines along the field borders that will need to be located for planning site access.

There will probably be buried power cables along with water and possibly sewers running along or beside Whimpwell Road that will need to be considered if excavating to provide the site access.

7.4. Field Conditions, Drains and Gates

The site visit was conducted after a wetter than average December. While the access tracks were puddled, the fields were well drained due to the sandy soil and gentle slopes. Standard construction methods of geotextile covered with stone or suitable fill is likely to be used for the working area and access roads.

8. CONCEPTUAL DESIGN & CALCULATIONS

Vattenfall have requested that this study examines two sets of variables for HDD Designs, a different number of ducts for HVDC or HVAC cables, and long or short exits. For HVAC a total of 12 cable ducts are required to accommodate both Vanguard and Boreas. For HVDC a total of 4 ducts are required for the two projects.

For the scenario of a short exit, the HDD is assumed to exit in the intertidal area at approximately mean sea level. For the long exit the HDD is assumed to exit at approximately -5.5m to -6.5m LAT (that is, 5.5 to 6.5m below LAT). The short HDD's are approximately 170m length. The long HDD's approximately 700m length. This long exit point is in an area where the bathymetry flattens off, indicating a more stable environment than the shallower seafloor closer to the coast.

For comparison, and to assist on future evaluation of the most beneficial HDD length for the project, the exit position for 1000m length HDD's exiting at approximately -9.5m LAT is also shown on the designs. The 1000m length represents a step change in HDD cost and risk because it is the distance at which forward (push) reaming with standard HDD equipment begins to exceed equipment capability. The result is a need for pull reaming to complete the HDD with a significant step up in the scale of offshore equipment (barge's or jack-up platforms) and the length of time the offshore equipment is needed. The main benefit of exiting in 9m water rather than 5m water is that it substantially increases the number of cable vessels that could be used for cable installation.

Figure 18.Pilot hole beach exit on a UK cable landfall project.

Figure 19.Pilot drilling string being pulled aboard on a UK project after an exit in 5m water.

The conceptual designs are based on low accuracy land elevations and seafloor bathymetry. The land elevations are interpolated from site observations correlated to OS Explorer Mapping 5m contours. The bathymetry is assumed based on navigational charts. Further design work will require improved accuracy levels. Lidar data or topographical surveys will be required for the chosen land and beach sites. A bathymetric survey will be required for the near shore / offshore areas.

The final exit points will need to account for a number of factors including consideration of working limits for marine installation techniques, surveyed bathymetry, predicted changes in seafloor bathymetry in the longer term, and the existing depth of loose sediment at the exit point.

The depth of sediment at the exit point needs to balance the requirements for marine installation techniques and minimising the risk of increased duct installation forces due to loose sediment being dragged into the borehole during installation. Ideally the vertical thickness of loose sediment at exit should be less than 4m; however previous landfalls have been installed without incident through 8m thickness of loose sand and cobble.

8.1. Conceptual Designs

The conceptual HDD designs are shown in Drawings 20171201RA-C/01 (HVAC) and 20171201RA-C/02 (HVDC). In sectional view the HVAC and HVDC designs are identical.

Beneath the beach and the sea, the design attempts to maintain 14m to 15m depth of cover. When further ground information becomes available and cabling requirements are known, this depth can be optimised. The process of optimising the depth will balance the risk of drilling fluid breakout against minimising depth to improve thermal losses from the cable.

The entry angle of the short and long designs has been set at 15 degrees for the conceptual designs. This is toward the higher end of normal entry angles, the typical range is 8 degrees to 17 degrees, but seeks to minimise the length of cable buried at depth beneath the fields. An entry angle of 10 degrees would increase the length of the HDD by 30m but on the long HDD would reduce the maximum depth of cover under the field by approximately 2m. This would slightly reduce cable pull in tensions and might have benefits in increasing thermal losses for the cable, although the shallower burial depth might be offset by the 30m additional buried length.

The design has a clearance of 3.5m below the SMP estimated 2055 toe of the cliff but there is scope to reduce this distance, and the depth of cover beneath the fields, to optimise the design if required. Similarly, if it is decided to design for a longer cable service life the entry points can be moved further inland; every metre moved adds approximately 1 year to the time taken for coastal retreat to expose the cable.

The radius of the short HDD's has been set at 300m which is within the tolerances of the proposed duct and capabilities of the drilling equipment. A lower radius could potentially be used but would need to be assessed against any increase in cable installation stresses.

The bend radius of the long HDD's has been set at 500m. This could potentially be increased to 750m or possibly 1000m for the entry radius if a 10 degree entry angle was used. However, it would require the entry point to move further from the coastline and add 30m of drilling length to the HDD's. The 500m radius is acceptable for the length of the HDD and expected drilling conditions. It is well within the tolerances of the duct.

8.1.1 Short HDD

In plan view 12 No. of short HDD's are possible for HVAC cables, assuming 30m separation at entry and 30m separation for each cable pair and 120m between circuits at exit on the beach. The position of the beach exit will need to be adjusted when accurate topographical information becomes available. This spacing is the maximum that can be achieved without extending the width of the site.

For the case of HVDC cables, the four HDD's are shown with 10m separation between a cable pair at entry and exit, and 120m between the projects (Vanguard and Boreas). These distances can be increased if required. There is also plenty of area available to move the entire site parallel to the coast to find the most suitable location.

8.1.2 Long HDD

In plan view 12 No. of long HDD's are possible for HVAC cables. The HDD's maintain 30m separation between a pair but fan out to provide 120m separation between circuits at exit.

The plan view design for the HVDC cables shows 4 ducts with 10m separation between a cable pair at entry, 20m at exit, and 120m between the projects (Vanguard and Boreas). The lower separation distances between the HVDC cables are based on the scope of works for this study and previous work with HVDC landfalls. The distances reflect the lower heat output from DC cables and therefore less need to ensure dissipation. If greater separations are required for the HVDC cables there is sufficient room to expand or move the sites and accommodate the changes.

8.2. Calculations

8.2.1 Drilling Forces and Rig Size

Drilling forces have been calculated for the different HDD lengths. For the short HDD the calculations assume 4 ½” drill pipe and 6 $^{1}/_{8}$” bit, this is likely to be the largest assembly used on this length, and 3 reaming passes. For the long HDD’s the calculations assume using the largest standard drill pipe, 6 $^{5}/_{8}$”, a 9 $^{7}/_{8}$” bit and 2 reaming passes.

HDD LENGTH	MAXIMUM DRILLING (ON BOTTOM) FORCES		
	Push (Tonne Force)	Pull (Tonne Force)	Torque (kN.m)
Short – 170m	7	3	8
Long – 700m	18	23	19
Long – 1000m	28	26	25
Note: Torque calculation assumes 3 reaming stages for short HDD, 2 reaming stages for long HDD’s			

Table 4. Indicative drilling forces for the short and long HDD options.

The limiting factor for most HDD drilling equipment is the Torque capability; for the 700m HDD the calculated torque for reaming 26” is 19kN.m. It is good practice to double the theoretical value to account for any spikes encountered in rough ground (e.g. gravel or cobbles), making 38kN.m the possible peak torque values.

The smallest HDD rig capable of the required torque would be a 100t (pull capacity) machine that typically have 40 kN.m torque available. These are termed maxi rigs. Most contractors would elect to use a larger machine and 150t to 300t machines are more likely to be used for the 700m and 1000m HDD options.

For the short HDD’s the HDD rig is likely to be a midi HDD rig capable of 15t to 40t pulling force and 15kN.m to 30kN.m torque.

8.2.2 Installation Forces

Duct installation forces have been calculated for the long and short HDD options. A summary of the results is given in Table 5 below and examples of the calculation sheet for the 700m length option are given in Figure 20 and Figure 21.

The calculation show that the long ducts should be water filled to minimise installation forces. The recommended maximum pulling force for 500mm SDR11 PE100 is 66.2 tonnes and this is well above the expected pulling force for water filled ducts.

It should be noted that a check of the suitability of the specified duct for operational forces has not been undertaken.

SUMMARY OF PULLBACK CALCULATIONS FOR HDPE 500 mm OD PIPELINE		
Vattenfall, Happisburgh - Short	**18th January 2018**	
Parameter	**500 mm, SDR11**	**Units**
Pipe weight, W_p	0.062	tonnes/m
Water Filled weight, W_{pw}	0.193	tonnes/m
Buoyant air filled weight, W_{ba}	-0.154	tonnes/m
Buoyant water filled weight, W_{bw}	-0.023	tonnes/m
Buoyant seawater filled weight, W_{bs}	-0.019	tonnes/m
Maximum Pullback Force - air filled	7.3	tonnes force
Maximum Pullback Force - water filled	7.7	tonnes force
Maximum Pullback Force - seawater filled	7.7	tonnes force
Maximum Pullback Force - open pipe	3.8	tonnes force

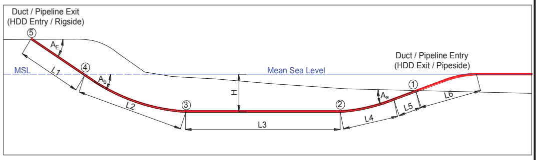
SUMMARY OF PULLBACK CALCULATIONS FOR HDPE 500 mm OD PIPELINE		
Vattenfall, Happisburgh - 700m	**18th January 2018**	
Parameter	**500 mm, SDR11**	**Units**
Pipe weight, W_p	0.062	tonnes/m
Water Filled weight, W_{pw}	0.193	tonnes/m
Buoyant air filled weight, W_{ba}	-0.154	tonnes/m
Buoyant water filled weight, W_{bw}	-0.023	tonnes/m
Buoyant seawater filled weight, W_{bs}	-0.019	tonnes/m
Maximum Pullback Force - air filled	64.1	tonnes force
Maximum Pullback Force - water filled	16.3	tonnes force
Maximum Pullback Force - seawater filled	15.1	tonnes force
Maximum Pullback Force - open pipe	8.6	tonnes force

SUMMARY OF PULLBACK CALCULATIONS FOR HDPE 500 mm OD PIPELINE		
Vattenfall, Happisburgh - 1000m	**18th January 2018**	
Parameter	**500 mm, SDR11**	**Units**
Pipe weight, W_p	0.062	tonnes/m
Water Filled weight, W_{pw}	0.193	tonnes/m
Buoyant air filled weight, W_{ba}	-0.154	tonnes/m
Buoyant water filled weight, W_{bw}	-0.023	tonnes/m
Buoyant seawater filled weight, W_{bs}	-0.019	tonnes/m
Maximum Pullback Force - air filled	87.8	tonnes force
Maximum Pullback Force - water filled	19.8	tonnes force
Maximum Pullback Force - seawater filled	18.1	tonnes force
Maximum Pullback Force - open pipe	11.4	tonnes force

Table 5. Summary of calculated installation forces for long and short HDD options.

PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, EMPTY DUCT
Simple outfall model for air filled pipe. Assumes water level in HDD is at MSL.
Assumes pipe is floating in sea and pulled in by HDD rig on land.
Base on method by Slavin as outlined by Plastic Pipes Institute
Includes Frictional Drag Forces, Capstan Forces, and Hydokinetic Forces

Project: Vattenfall, Happisburgh - 700m
Modelling Date: 18th January 2018



Pipe specifications and Borehole dimensions			
Reamed hole diameter	D_H	26 Inches	660.4 mm
Pipe outer diameter	OD	500 mm	19.7 inches
SDR		11	
Wall thickness	t	45 mm	1.8 inches
Pipe internal diameter	ID	409 mm	16.1 inches
Reamed : Pipe ratio		1.32 (1.5 typical)	
Density	HDPE	0.952 t/m3	0.034 lbf/in^3
Cross sectional area		64909 sq mm	101 sq inches
Design minimum radius	R_{min}	500 m	1640 ft

Friction and drilling fluid characteristics			
Coefficient of sea floating friction	m_g	0.05	(suggest 0.05 for tow lines)
Coefficient of borehole friction	m_b	0.4	(typically 0.25 - 0.50)
Hydrokinetic pressure	p	42 kPa	(28-55 kPa normally)
Specific gravity of the mud slurry	g_b	1.1	(Bentonite typically 1.05 - 1.20)
Density of fresh water	r_w	1.0 t/m3	
Density of seawater	r_s	1.025 t/m4	

HDD DESIGN

Section of borehole above Mean Sea Level (MSL)			
Length from entry to MSL elevation	L_1	52 m	
Angle	A_E	15 deg	

Section of borehole below Mean Sea Level (MSL)			
As drilled exit angle (pipeside)	A_a	10 deg	0.175 rad
Angle (rigside) at MSL	A_b	15 deg	0.262 rad
Drilled MSL tangent + curve length	L_2	115 m	377.3 ft
Horizontal tangent length	L_3	415 m	1361.5 ft
Drilled exit curve length	L_4	93 m	305.1 ft
Exit tangent	L_5	26 m	85.3 ft
Vertical depth (relative to MSL)	H	18.5 m	60.7 ft
Length from exit to sea level (MSL)	L_6	55 m	180.4 ft

Minimum radius		
Minimum Installed Radius	38 m	
Minimum overbend radius	25 m	

Note that SDR of HDPE pipe should be selected to pass long and short term ring deflection, tensile pressures etc

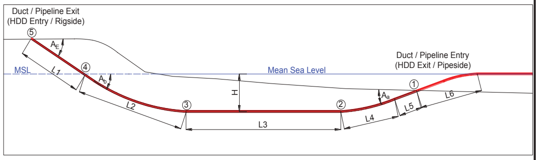
Dead and buoyant pipe weights				
Pipe weight, W_p	0.062 tonnes/m		42 lb/ft	
Buoyant empty weight, W_b	-0.154 tonnes/m		104 lb/ft	^
Buoyant filled weight, W_b	-0.023 tonnes/m		15 lb/ft	^
Total pipe length	649 m			
Total pipe weight	40 tonnes		88,228	lbs
Total pipe weight submerged	-100 tonnes	-	220,154	lbs
Total pipe weight of submerged tail in sea	-8 tonnes	-	17,422	lbs

PULLBACK FORCES			
Combined Drag and Capstan Forces at:			
Point 1	10 t	21,881	lbs
Point 2	48 t	105,079	lbs
Point 3	57 t	125,275	lbs
Point 4	62 t	135,835	lbs
Hydrokinetic Force	0.3 t	690	lbs
Max Force from submerged section	62.1 t	136,526	lbs
Gravitational pull component	0.8 t	1,833	lbs
Frictional pull component	1.2 t	2,737	lbs
Pipe unlikley to slide downhole if unsecured			
Force from dry section (empty pipe)	2.1 t	4,571	lbs
Maximum force through submerged hole	62.1 t	136,812	lbs
Maximum force through dry hole	2.1 t	4,571	lbs
Maximum Force	64.1 t	141,383	lbs

Figure 20. Example calculations for air filled duct installed for 700m Long HDD.

PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, WATER FILLED DUCT
Simple outfall model for air filled pipe. Assumes water level in HDD is at MSL.
Assumes pipe is floating in sea and pulled in by HDD rig on land.
Base on method by Slavin as outlined by Plastic Pipes Institute
Includes Frictional Drag Forces, Capstan Forces, and Hydokinetic Forces

Project: Vattenfall, Happisburgh - 700m
Modelling Date: 18th January 2018



Pipe specifications and Borehole dimensions			
Reamed hole diameter	D_H	26 inches	660.4 mm
Pipe outer diameter	OD	500 mm	19.7 inches
SDR		11	
Wall thickness	t	45 mm	1.8 inches
Pipe internal diameter	ID	409 mm	16.1 inches
Reamed : Pipe ratio		1.32 (1.5 typical)	
Density	HDPE	0.952 t/m3	0.034 lbf/in^3
Cross sectional area		64909 sq mm	101 sq inches
Design minimum radius	R_{min}	500 m	1640 ft

Friction and drilling fluid characteristics			
Coefficient of sea floating friction	m_g	0.05	(suggest 0.05 for tow lines)
Coefficient of borehole friction	m_b	0.4	(typically 0.25 - 0.50)
Hydrokinetic pressure	p	42 kPa	(28-55 kPa normally)
Specific gravity of the mud slurry	g_b	1.1	(Bentonite typically 1.05 - 1.20)
Density of fresh water	r_w	1.0 t/m3	
Density of seawater	r_s	1.025 t/m4	

HDD DESIGN

Section of borehole above Mean Sea Level (MSL)			
Length from entry to MSL elevation	L_1	52 m	
Angle	A_E	15 deg	

Section of borehole below Mean Sea Level (MSL)			
As drilled exit angle (pipeside)	A_a	10 deg	0.175 rad
Angle (rigside) at MSL	A_b	15 deg	0.262 rad
Drilled MSL tangent + curve length	L_2	115 m	377.3 ft
Horizontal tangent length	L_3	415 m	1361.5 ft
Drilled exit curve length	L_4	93 m	305.1 ft
Exit tangent	L_5	26 m	85.3 ft
Vertical depth (relative to MSL)	H	18.5 m	60.7 ft
Length from exit to sea level (MSL)	L_6	55 m	180.4 ft

Minimum radius		
Minimum Installed Radius	38 m	
Minimum overbend radius	25 m	

Note that SDR of HDPE pipe should be selected to pass long and short term ring deflection, tensile pressures etc

Dead and buoyant pipe weights				
Pipe weight, W_p	0.062 tonnes/m		42 lb/ft	
Pipe weight filled, W_{pw}	0.193 tonnes/m		130 lb/ft	
Buoyant empty weight, W_b	-0.154 tonnes/m		104 lb/ft	^
Buoyant filled weight, W_b	-0.023 tonnes/m		15 lb/ft	^
Total pipe length	649 m			
Total pipe weight	40 tonnes		88,228	lbs
Total pipe weight submerged	-15 tonnes	-	32,483	lbs
Total pipe weight of submerged tail in sea	-1 tonnes	-	2,571	lbs

PULLBACK FORCES			
Combined Drag and Capstan Forces at:			
Point 1	3.2 t	7,030	lbs
Point 2	7.7 t	16,974	lbs
Point 3	8.8 t	19,370	lbs
Point 4	9.5 t	20,844	lbs
Point 5	16.3 t	35,872	lbs
Hydrokinetic Force	0.3 t	690	lbs
Max Force from submerged section	9.8 t	21,534	lbs
Gravitational pull component	2.6 t	5,733	lbs
Frictional pull component	3.9 t	8,559	lbs
Pipe unlikley to slide downhole if unsecured			
Force from dry section of hole (full)	6.5 t	14,293	lbs
Maximum Force	16.3 t	35,872	lbs

Figure 21. Example calculations for water filled duct installed for 700m Long HDD.

9. HDD SITE REQUIREMENTS

9.1.1 Site Layout

Drawing No. 20171201RA-C/01 in Appendix A indicates a conceptual site setup for the long HVAC option that results in the maximum working area. It assumes a maxi (>100t) HDD rig drilling 12 No. HDD's. The drillings are divided into two separate working areas to allow for the Vanguard and Boreas HDD's to be conducted separately if necessary. The dimension of each of the two working areas, including parking, is 175m x 50m. The working areas have potential to be reduced if the separation distance between the ducts is reduced; the scope of works for this study suggested 20m separation which would reduce the working area for each project to 100m x 50m.

The short HVAC option would be drilled by a smaller midi sized rig with approximately half the ancillary equipment allowing the depth of the working area could therefore be reduced from 50m to 35m.

For the option of long HVDC HDD's, presuming the 4 No. HDD's are to be drilled from the same site, the working area for each project (Vanguard and Boreas) could be 60m x 50m assuming that there is 10m separation between HDD's at entry. If both projects were to be completed at the same time a working area of 120m x 50m would be used. The indicative site layout is shown in Drawing No. 20171201RA-C/02 in Appendix A.

For the short HVDC HDD's the working area could be reduced to 35m x 40m for each project.

The working pad on similar sized HDD projects is normally geotextile covered with stone or clean hardcore. Topsoil is stripped and stockpiled prior to laying the geotextile and it is often stored in a strategically positioned bund to assist in reducing the impact of noise on nearby neighbours. For the HVAC site it might be stored on the north-western side of the site to assist in noise attenuation.

Provision should be made on site for settlement ponds to contain site runoff and for silt fencing to clean water to acceptable standards before any discharge.

9.1.2 Noise & Lighting

The impact of noise, vibration, and lighting is discussed in Sections 6.2, 6.3, and 6.4. The nearest permanent residences are 300m from site on Lighthouse Lane; some form of noise mitigation will be required if 24-hour working is planned for the long HVAC option. It is recommended that prior background noise monitoring is undertaken as part of environmental studies to allow planning of noise mitigation.

The short HVAC and HVDC options are unlikely to require 24 hour working and are sufficiently removed from residences for day and evening work.

The long HVDC option is sufficiently removed from any nearby permanent residences and 24 hour working should not cause nuisance.

The effect of lighting on local residents and coastal shipping can be mitigated by strategic positioning of lighting and by installation of boarding to shield residents from direct light.

10. DRILLING METHODOLOGY

The conceptual design of the HDD's is a relatively straightforward landfall drilling with the ground expected to be predominantly silty gravelly CLAY for the short HDD's and initial section of the long HDD. The majority of the long HDD is expected to be drilled in silty SAND. The following methodology outlines the most commonly used techniques for this type of HDD however tenderers might suggest variations or alternative methods for some aspects of the HDD.

10.1. Site Setup

Prior to the arrival of HDD equipment the vehicle access, drilling pad and working area at the entry site shall be prepared. Any uneven ground should be made level and access should be suitable for the haulage equipment. Topsoil should be removed and stockpiled for reinstatement after completion of the works. If necessary, the access track will be upgraded with bog mats or geotextile and hardstanding material.

Any drainage work required to make the site safe for working and to prevent environmental damage from site runoff should be complete.

All services, below ground and above, should be located and protected from damage or isolated as needed.

A water supply of suitable quality and flow rate will be used for mixing drilling fluid. This will either be a nearby hydrant point, or possibly bore water from irrigation supplies if the quality is suitable and it is permitted to use the required quantity. Indicative usage while drilling is $10m^3$ per shift with an upper extreme of $40m^3$ per shift. Water from hydrant sources can be transferred via temporary hoses or HDPE pipelines. Alternatively, it can be brought to site with tractor and bowser or by tanker.

A traffic management plan and haulage route for heavy equipment should be implemented prior to arrival of equipment.

For a maxi HDD setup the equipment typically comes in 20 loads (the equivalent of standard shipping containers, 12m x 2.5m x 2.5m) at up to 24t weight each load. The rig itself is usually transported on a low loader and can be up to 16m in length with a load weight of up to 46t, but it depends on the rig manufacturer and type. The 20 loads are typically delivered over two days with a 250t crane used for offloading and positioning.

The entry point should be accurately surveyed and clearly marked, as should a number of alignment pegs for positioning of the rig and points for any surface tracking cable, if it is to be used.

An anchor block or sheet piled anchor will be required at the front position of the rig to ensure stability when drilling and installing the duct. Anchor blocks are typically 4m x 2m x 2m depth poured concrete blocks with steel I beams set in them to allow connection to the front foot plate of the HDD rig. If the superficial deposits are sufficiently deep sheet piles connected to a steel I beam might be used in place of a poured concrete block. The final specification of the anchor block or sheet piles should be designed to accommodate the expected drilling and installation forces imparted by the HDD rig.


Figure 22. A standard HDD maxi rig being delivered to site.

Personnel on the drill site should wear standard PPE including safety boots and hard hats. Personnel working on the rig will need gloves for manual handling and appropriate eye protection when welding, grinding, etc. The mud man on the drilling fluid mixing unit will need to wear appropriate hand and eye protection and dust masks when handling powdered bentonite and additives and complete PPE with coveralls if caustic soda is used to adjust the fluid pH.

Prior to the commencement of drilling barriers should be placed around any open excavations and measures taken to prevent public access to the site. High pressure hoses from the mud pumps should have appropriate safety lanyards. Personnel should hold the relevant permits and licences for any plant and equipment they are operating.

Indicative site layouts for the HVAC and HVCD HDD options are shown on Drawing No's. 20171201RA-C/01 and 20171201RA-C/02.

Figure 23. Example HDD site layout. Fluid storage lagoons are sometimes replaced with storage tanks.

The north-western end of the HVAC site will probably require noise mitigation for 24 hour working to minimise the impact on neighbours. The HVDC site is sufficiently removed from permanent residences and noise mitigation is only likely to use strategic placement of plant, machinery and site containers. Consideration will need to be given to working times during holiday periods for nearby residences used as holiday homes.

Because of the proximity of Happisburgh light house any night workings will need to plan lighting so that shipping navigation is not impacted; liaison with relevant port authorities will be required.

Figure 24. Example HDD rig of the maxi size likely to be used for the long HDD's.

Figure 25. Example HDD rig of the midi size likely to be used for the short HDD's. A sheet piled rig anchor is visible on the left.

10.2. Casing

Casing might be required to stabilise any loose superficial deposits overlying the bedrock at the entry point. Based on the existing Ground Investigations contractors might drill without any mitigation but have provision for insertion of casing if hole stability in the upper zones proves problematic. The length of casing might be around 30m, but will depend on the ground encountered in the particular HDD. Loose silty sand is the lithology are mostly likely to need support, glacial till (silty gravelly clay) the least.

The casing installation will either be washed over the pilot drill, trenched in prior to pilot drilling, or pre-installed using a casing hammer. Ideally the casing should be of larger diameter than the final reamed hole size. After duct installation the casing can be removed, generally by being pulled out by the drilling rig with assistance from a casing hammer (reversed) if required.

10.3. Pilot Hole

Prior to drilling an entry pit is excavated; generally several metres square and 1.5m to 2.0m in depth. The entry pit has the dual purpose of containing drilling fluid returns and ensuring any buried services are exposed prior to drilling. A pump in the pit transfers fluid to the mud recycling unit.

The HDD drilling contractor is likely to use a jetting assembly and jetting bit for the downhole drilling assembly on this project (Figure 26). If they consider the presence of concretions, cobbles and boulders to be a significant risk based on ground investigations, they might opt for a jetting assembly with a tri-cone bit. A tri-cone drilling bit powered by a downhole motor (DHM) is normally only used for drilling in rock.

A jetting assembly uses the high pressured jets omitted from the nozzles in the bit to hydraulically excavate the ground ahead. To drill a straight section of hole the entire string of drilling rods is rotated. To drill a curved section of hole the angled shoe of the bit is oriented and then pushed forwards to steer in the required direction. In stiff clays a tri-cone bit might be used to better cut away the ground and the function of the jetted fluid is more to clear away the cuttings.

On occasion the drilling assembly may need to be torqued using chain tongues. This operation should only be performed by experienced personnel and all non-essential personnel should stand well clear.

Behind the jetting assembly are guidance sensors that allow tracking of the borehole position during the pilot hole drilling. The sensors are connected to processing equipment at the surface by an insulated cable running through the centre of the drill rods. The guidance system will probably either be a Gyro system or a Magnetic Guidance System (MGS) with surface tracking. If an MGS is used tracking cable will be placed at points along the surface alignment of the bore to give an independent position of the HDD. On this project it is likely that the tracking cable would be extended to the low tide level but will not be required all the way to exit.

During drilling operations the drilling rods will be turning at around 60-90 rpm. All personnel should stand clear of the rotating string. Loose clothing should be avoided for those working around the rig; high visibility vests tend to be a risk in these conditions and should be replaced with high visibility clothing or jackets.

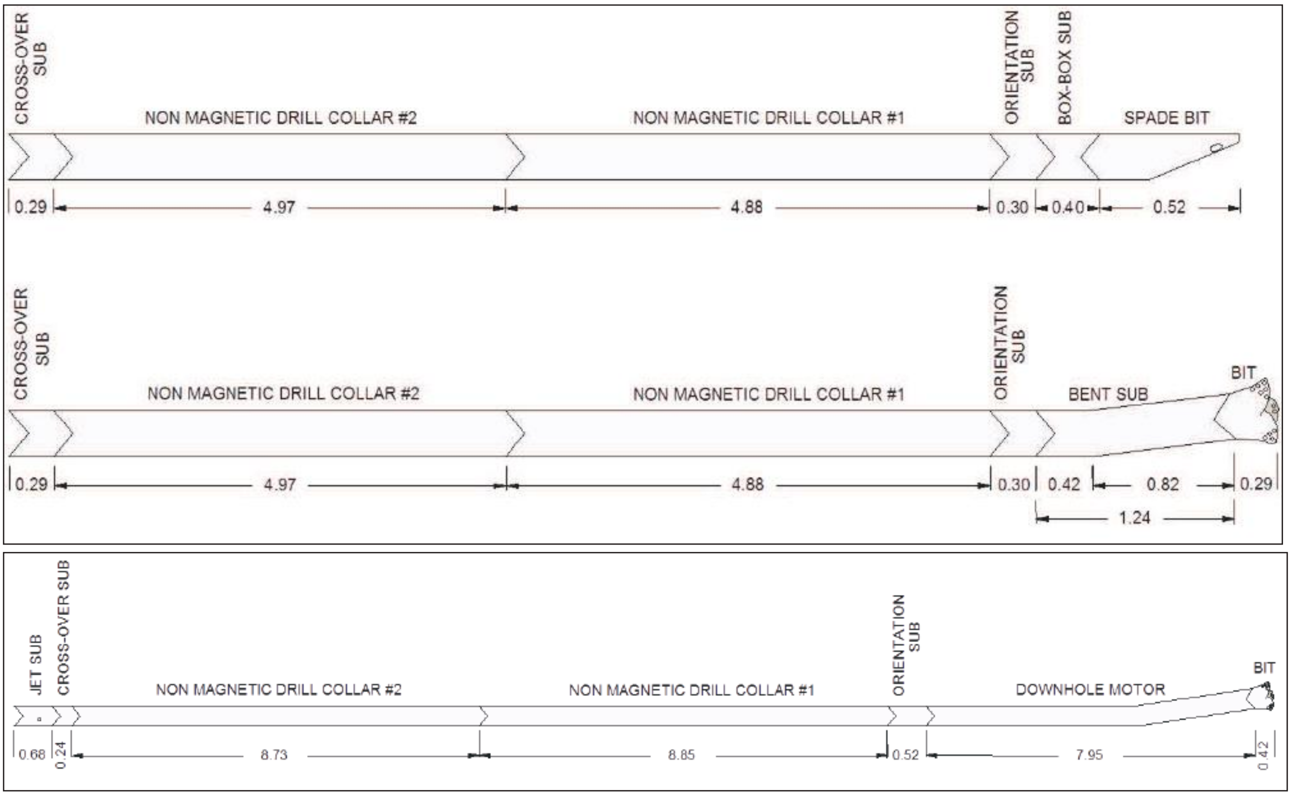


Figure 26. Example drilling assemblies; Jetting assembly with spade bit at top, jetting assembly with tri-cone bit in centre, and downhole motor assembly with tri-cone bit at bottom.

When a drilling rod has been drilled down the rod is disconnected from the drive head. The drive head is pulled back to the top of the mast and a new drill rod is added. For the option of long HDD's a wireline cable inside the drilling rods is extended and connected before the new drilling rod is torque ready for drilling down. For the short HDD's the guidance system will probably be battery powered with wireless transmission of data so a wireline connection is not required.

During the procedure of adding and removing drill rods there is potential for accidents involving pinch points and rotating equipment. Only trained and experienced rig hands should be working on the rig at these times.

Downhole positional surveys are taken at the end of each drilled rod. While a new drilling rod is added the guidance engineer plots the position of the HDD and formulates instructions for drilling the next rod so that the bore remains on course. The driller will adapt drilling forces as the rod progresses to effect efficient and stable drilling. The driller keeps a log recording the drilling parameters and any notes on ground conditions for each rod. The pilot drilling process continues until exit is reached.

On long crossings or in hard ground the drilling rig can be exerting 25 tonne or more force on the drill rods. On rare occasions the drill rods can suddenly buckle, potentially deflecting sideways and injuring bystanders. Personnel should stand well to the side of the drill string during operation.

If the pilot drill deviates too far off course at any point the bit can be pulled back (by removing drilling rods) to a suitable point. A sidetrack off the old borehole can then be cut and the new section of hole steered onto the correct course.

10.4. Drilling Fluids

The drilling fluid serves many purposes. Its primary role is to create a gel thick enough to suspend soil and rock cuttings and carry them out of the hole. In addition, the drilling fluid hydraulically excavates soil in soft ground, powers the downhole motor in hard ground, cools the drilling equipment, clears debris from the drilling bit and face, seals the perimeter of the borehole in porous ground and lubricates the borehole to reduce friction on the drilling equipment.

The drilling fluid predominantly used in HDD is a mix of water and a naturally occurring swelling clay, bentonite. On occasions the chemical properties of the drilled soil or rock reduce the effectiveness of the drilling fluid. As a result, additives such as natural xanthum gum and gypsum are sometimes added to improve the properties of the fluid.

Bentonite is supplied in powdered form, usually in 1 tonne bulk bags. The bentonite is fed into a hopper where it is mixed with water circulated through the mixing tank. From the mixing tank the fluid is transferred to the active tank. High pressure pumps then pump the fluid downhole. The operator of the fluid system (the “mud man”) will need to wear appropriate hand and eye protection and dust masks when handling powdered bentonite and additives. If caustic soda is used to adjust the fluid pH complete PPE with coveralls should be worn.

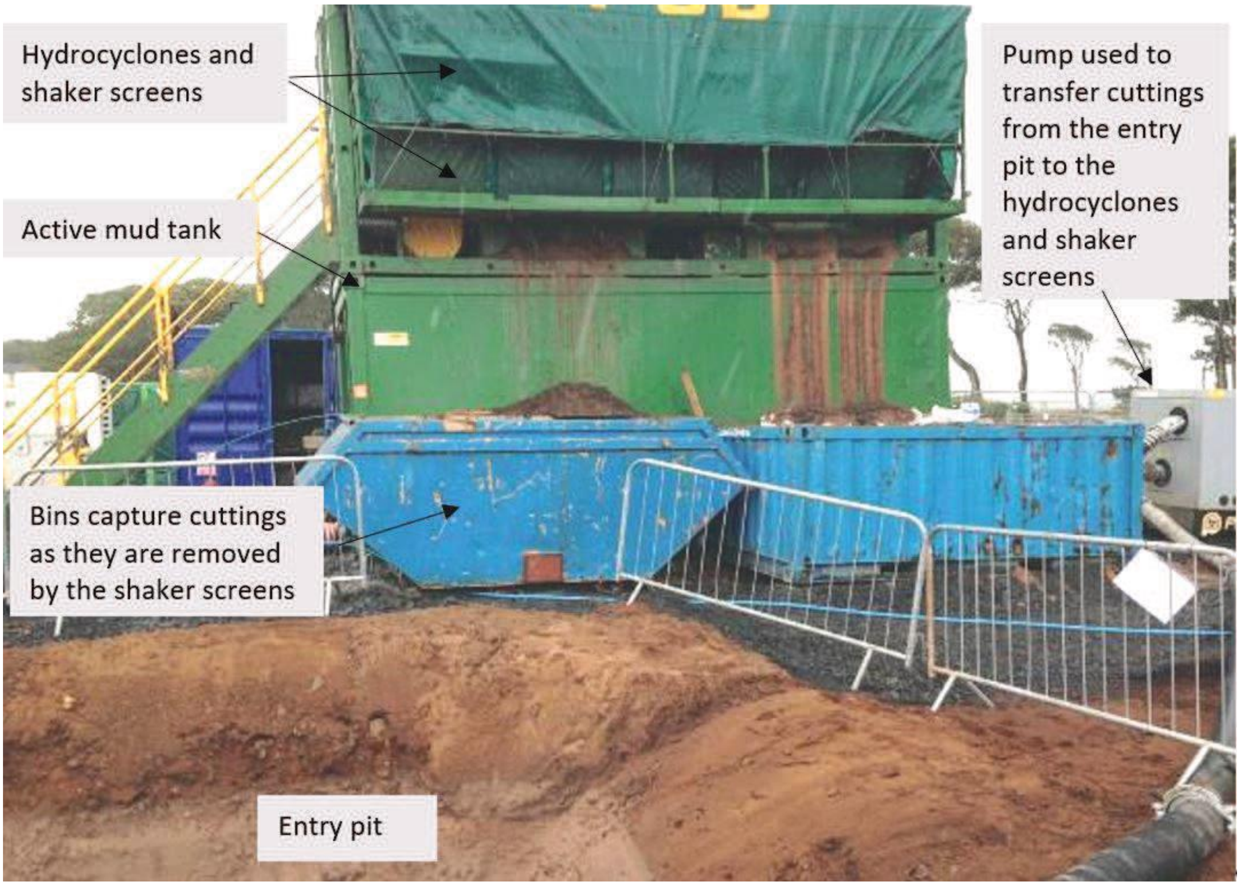


Figure 27. A drilling fluid recycling unit with components indicated.

The bentonite drilling fluid is circulated down through the drill rods and back up the outside of the rods in the annulus of the borehole. Exiting into the entry pit, the fluid is then pumped to the mud recycling unit (Figure 27) where hydro-cyclones and shaker screens remove cuttings. The cuttings accumulate beneath the shakers and are usually disposed of at landfill sites. The cleaned drilling fluid transfers to the active tank ready for circulation through the hole.

The mud man will keep records of drilling fluid parameters at regular intervals and monitor drilling fluid volumes so that any losses to the formation are identified. The driller will monitor and record downhole fluid pressures and returns to the entry pit to also ensure losses are recognised quickly.

During pilot hole drilling in soft ground the use of a Pressure While Drilling (PWD) tool is recommended to reduce the risk of breakout, formation damage, and equipment becoming stuck due to inadequate hole cleaning. A PWD tool is located with the downhole surveying assembly behind the downhole motor and measures the annular pressure in the borehole; the pressure of the drilling fluid flowing between the outside of the drill rods and the borehole wall. It is a standard add-on module for Gyro and MWD guidance systems.

10.5. Reaming

Once the pilot hole is completed the bit, downhole motor, and steering equipment is removed. For landfall projects exiting on the seafloor (the long HDD options on this project) the pilot hole is usually stopped short of the exit point (in this case perhaps 30m short) so that drilling fluid returns are not lost to the sea. The pilot hole is then enlarged using forward reaming; the reamer / hole opener being advanced from entry towards exit. The drilling fluid is pumped down through the drilling rods onto the cutting face of the reamer and then carries the cuttings back up the hole to the entry pit. From the entry pit the fluid is passed through the recycling unit to remove the cuttings before being pumped downhole again.

The safety precautions for pilot hole drilling apply to reaming operations; keeping personnel clear of the drill string during operations and only trained personnel on the rig. If chain tongues are used they should only be operated by experienced personnel and all non-essential personnel should stand well clear.

The HDD will require several reaming passes with progressively larger diameter reamers until the final hole size is reached. A final decision on the diameter and number of reaming stages is usually made by the drilling contractor once ground conditions have been evaluated from drilling the pilot hole. A possible configuration for this project would be a 12.25” (311mm) pilot hole with reaming stages of 18” and 26” (457mm, 660mm).

To ensure the forward reaming follows the pilot hole, one or more rods and a rounded “bullnose” is usually placed in front of the reamer or hole opener. For the larger diameter reams a front centraliser is often used to ensure that the reamer cuts evenly, and a rear centraliser is often used to ensure evenly distributed force on the reamer or hole opener.

There are a variety of types of reamers and hole openers designed for different ground conditions (Figure 28). For clayey conditions a flycutter is likely to be used. For sandy ground, particularly loose sands, barrel reamers are often used although for forward reaming a flycutter might be judged more suitable in denser sands.

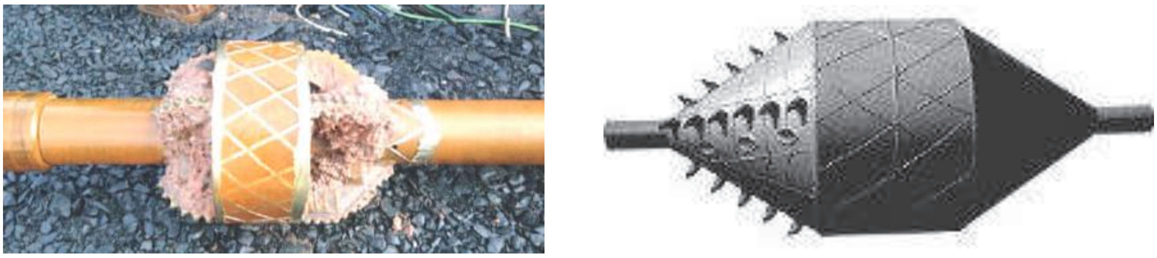


Figure 28. Typical flycutter hole opener (left) and barrel reamer (right)

Once all stages of the forward reaming for the long HDD option are completed to the end of the pilot hole, the pilot hole is then extended to the exit point. At this stage the hydrostatic head of drilling fluid will be lost into the sea. The remainder of the pilot hole is then opened up to the final diameter using conventional (pull) reaming. The reamer is attached at the exit point and pulled towards the entry point. Drilling fluids are pumped from the HDD rig through the drilling rods to the reamer where they remove the cuttings and flow into the sea.

The conventional (pull) reaming of the long HDD option will require an offshore barge or jack-up platform at the exit point during this stage of the operations.

Estimated volumes of fluid losses for the long 700m HDD option are provided in Section 12.3. The volumes provided are for the fluid itself. The volume of sediment carried in the fluid is equivalent to the volume removed from the bore. For the case where most fluid is released, pull reaming the final 30-40m of the HDD, the 120m^3 of fluid released will contain an equivalent solids volume of approximately 14m^3.

For the short HDD option conventional (pull) reaming will probably be used for all hole enlargement, with returns captured at the exit point and transported to the entry point for recycling. Transport of the fluids is normally either by tractor and bowser or pumped through a temporary 100mm PE pipeline.

10.6. Duct Installation

For HDD landfalls the traditional duct installation method is to pull the HDPE into the hole from exit towards entry. This is the most suitable method of installation for this project; however a pushed installation is also described for comparison.

10.6.1 Pulled Installation

For a pulled installation the ducts are floated into position at the exit point, flooded with water, and then pulled into the reamed borehole for installation (commonly termed "pullback"). The ducting can either be fabricated as a single length (by Pipelife in Norway) and towed to a mooring position nearby awaiting installation, or it can be fabricated at a nearby convenient location by butt fusion welding 12m or 18m lengths to form the duct. This can then be towed to the exit position when required. A typical setup for butt fusion welding of PE pipe is shown in Figure 29.

Prior to installation a cleaning run is preformed either with a reamer of equal or slightly smaller diameter than the final hole size, in the case of a 40" reamed hole a 36" reamer might be sufficient.

The duct will be prepared for installation by attaching a pulling head (Figure 30) and the duct ballasted by filling with water to reduce its buoyancy.

The pulling assembly will consist of the drill rods connected to a reamer of slightly larger diameter than the pipeline. Connected to the reamer is a swivel of adequate strength for the expected pullback forces. When the pulling assembly is torqued to the drill rods the pulling head of the pipeline is bolted to the swivel and pullback can begin.

Figure 29. Typical setup of PE butt fusion welder

Figure 30. Drilling rod, swivel, pulling head and duct being pulled into the entry pit

Pullback proceeds by pulling back and removing a drilling rod then connecting onto the next drill rod and repeating. During pullback the ducts will displace bentonite fluid from the borehole. In this case the entry point is approximately 5-10m above sea level so most of the displaced fluid will flow out into the sea at the exit point.

During pullback the driller will monitor pulling forces to ensure the maximum allowable pulling force for the pipeline is not exceeded. When the pulling assembly reaches the drilling rig it will be disconnected and removed. The pulling head is usually connected to the rig anchor for a period of 12 hours after pullback to ensure that any stretch in the HDPE is recovered without losing the head of the duct downhole.

10.6.2 Pushed Installation

Pushed installations are traditionally used for steel pipelines on landfalls drilled in rock but have also been performed on a number of large (>300mm) diameter HDPE installations in rock. For this project a pushed installation would only be preferable if the seafloor contained a considerable thickness of gravel or cobble that might be dragged into the borehole during conventional pullback. Based on the existing offshore survey information such a scenario is unlikely.

A pushed installation requires either a proprietary pipe pusher, modification to the HDD carriage to allow pushing of the HDPE or, if the push forces are low, excavators or side booms with slings to move the duct. For longer installations the push can be assisted by a cable and pulling head at the exit point to guide the head of the HDPE along the borehole. In this case a workboat would probably provide sufficient tension in the duct.

The duct will need to be filled with water as it is pushed into the hole to reduce the buoyancy of the duct in the section of hole below sea level. The two common methods of ballasting are to either fill the seaward end using a smaller diameter PE line inside the duct, or to push in the pipe with an open head, allowing fluid to enter as the duct is installed. In the latter method the line is cleaned by pigging following installation.

An additional consideration for pushed installation is the area available for duct stringing on the land. There is sufficient area to manage a 700m length duct, however a longer duct would require special measures to cross Whimpwell lane or to be curved back around on itself. The bending radius of the pipe will allow this but it will require additional engineering and machinery during the installation.

10.7. Marine Support Works

For the long HDD's with exit points below the low water mark the operations at exit side will entail offshore works. The offshore equipment will be needed during the conventional reaming of the final section of the HDD and pulled duct installation operations. The approach taken to the offshore works varies between contractors and their preferred method of working will depend on their previous experiences.

On previous landfalls exiting in this depth of water a range of methods have been used from large barges to smaller scale legged or jack-up barges. At the small-scale end are workboats with divers used to retrieve and connect equipment. As a minimum they will be required to locate and attach lifting equipment to the drilling string. The drilling bit and assembly can then be pushed out and lifted onto a barge, platform or workboat to allow disconnection and connection of reamers and pulling heads.

The 700m length HDD's might not need divers if barges or jack ups are used; in reasonable water conditions the equipment should be visible and reachable with slings in order to lift it on board. The HDD typically exits within a tolerance of 1-2m laterally and 5m longitudinally of the planned exit point and this is also helpful in remote retrieval. The pilot exit on a 1000m HDD length however, will probably bend over to lay flat on the sea floor and require divers or submersibles to attach a line and bring it on board.

These marine operations will be required from the time that the drilling bit is punched out onto the seafloor until duct installation is completed. The operations may also include laying of concrete mattresses over the tail of the duct to protect it awaiting cable installation.

Figure 31. Large barge with four point anchoring. On the right hand side of the barge the duct can be seen being pulled into the HDD. The water depth is approximately 4m.

11. HDD RISK ASSESSMENT

A High-Level Risk Register has been compiled for the HDD landfalls. It intends to address environmental, safety, and project risk and does not differentiate between the long and short, HVAC and HVDC options.

The risk assessment method outlines the level of risk, prioritised in accordance with their probability and severity and classified into a risk category.

Probability (P)

Probability of Risk	1. Remote	Unlikely but conceivable
	2. Possible	May occur, could well occur
	3. Probable	May occur several times, occurs frequently

Severity (S)

Severity of Risk	1. Minor	*H&S:* Injury with short term effect, not reportable under RIDDOR. Environment: Nuisance to fauna and flora. *Project:* Minor changes required to achieve construction objectives with low cost and/or delivery implications
	2. Severe	*H&S:* Major injury or disability or ill health with long term effect reportable under RIDDOR, single fatality. *Environment:* Potentially fatal to fauna and flora for days / weeks. *Project:* Major changes required to achieve construction objectives with significant cost and/or delivery implications.
	3. Extreme	*H&S:* Multiple fatalities. *Environment:* Detrimental to local ecosystem for months / years *Project:* Catastrophic impact to construction objectives.

Risk Category (R)

PROBABILITY	Minor	Severe	Extreme
Remote	1	2	3
Possible	2	4	6
Probable	3	6	9

1 – 2 Risk is controlled as far as is reasonably practical, no further control measures necessary
3 – 4 Risk is controlled as far as is reasonably practical
6 – 9 Hazard should be avoided

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
		P	S	R		P	S	R
1	Downhole failure of drilling equipment	2	3	6	Check of all drilling equipment before being run into hole	1	2	2
					Trip out to check condition of equipment after set number of hours recommended by manufacturer / supplier	1	2	2
					Monitoring and recording of drilling forces to ensure they are within the tolerances of the equipment	1	2	2
					Ensure sand content of drilling fluid is minimised to reduce abrasive wear	1	2	2
					Fishing for equipment lost in hole	2	2	4
2	Accumulation of cuttings in borehole leading to equipment stuck in hole	2	3	6	Monitoring the volume of cuttings removed from the HDD against volume drilled	1	2	2
					Trained mud engineer in charge of drilling fluids	1	2	2
					Real time downhole Annular Pressure Monitoring to identify restrictions in borehole annulus and trigger remedial action	1	2	2
3	Drill unable to advance because of cobbles or obstructions	1	3	3	Sidetrack around obstacles (laterally or horizontally)	1	3	3
					Additional ground investigations to identify zones	1	3	3
4	Breakout of drilling fluid to the surface during pilot drilling	2	2	4	HDD Design has sufficient depth below surface for the expected ground conditions	1	2	2
					Monitoring of drilling fluid returns and volumes to warn of inadequate hole cleaning	2	2	4
					Drilling fluid to be of sufficient viscosity and properties for the ground being drilled	2	2	4
					Real time downhole Annular Pressure Monitoring to warn of over-pressuring by drilling fluid	1	2	2
					Have Lost Circulation Materials available on site to seal any breakout	2	2	4
					Grouting if necessary	1	2	2

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
5	HDPE duct stuck during pullback	2	3	6	Hole cleaning run(s) performed before pullback	1	3	3
					Installation forces monitored	1	2	2
					Safe pull limit adhered to	1	2	2
6	Release of drilling fluid to sea when drilling out exit	3	2	6	Stopping point of pilot hole considers ground conditions found during pilot drilling	2	2	4
					Drilling fluid pump rate reduced when ground becomes soft	1	2	2
					Evaluate use of alternative drilling fluid or water	1	2	2
7	Breakout of drilling fluid to the sea during forward reaming	2	2	4	Monitoring of drilling fluid returns and volumes to warn of inadequate hole cleaning	2	2	4
					Drilling fluid to be of sufficient viscosity and properties for the ground being drilled	2	2	4
					Pilot hole stopped in competent ground before exit point and only advanced to exit when reaming to that point is completed	1	2	2
					Lost Circulation Materials available on site to seal any breakout	2	2	4
					Grouting if necessary	1	2	2
8	Ground Collapse in borehole due to loose / weak ground or blowing sands	2	3	6	Ensure drilling fluid characteristics are suitable for ground conditions (e.g. viscosity, fluid loss / filter cake)	2	2	4
					Real time downhole Annular Pressure Monitoring to avoid damage to ground by over-pressuring with drilling fluid	1	2	2
					HDD designed to drill in the most suitable ground conditions	1	2	2
					Use of temporary casing in any unstable areas near entry	1	2	2
					Grout any areas of instability downhole	1	2	2
9	Reactivation of historic feature causing damage to duct or installed cable	1	3	3	Review and expert assessment of any risk posed by the structure	1	3	3
					Surface monitoring	1	3	3
					Design cable to accommodate movement	1	3	3
					Site HDD's outside zone	1	2	2

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
10	Unthreading from downhole equipment during back reaming due to insufficient make-up torque applied to connections on barge / workboat	2	2	4	Competent personnel on barge / workboat making drillpipe / assembly connections	1	2	2
					Drilling technique to maintain consistent torque and avoid over-spinning	2	2	4
					Use of cradles to assist in aligning drill rods	1	2	2
					Hydraulic breakout unit installed on barge / workboat	1	2	2
11	Forward reaming fails to follow pilot hole	2	2	4	Use of sufficiently long lead rods in front of stabiliser	1	2	2
					Use of a passive tool on lead rods (e.g. bull nose)	1	2	2
					Monitoring of drilling forces during forward reaming and comparison to pilot hole rate of penetration	1	2	2
					Trip out and survey reamed hole if in doubt	1	2	2
12	HDPE duct is damaged during pullback	2	2	4	Design to avoid unsuitable ground conditions if possible	1	2	2
					Cleaning run satisfactorily completed before pullback	1	2	2
					Monitoring of forces during pullback operations	1	2	2
					Duct removed, borehole reconditioned, new or repaired duct installed	1	2	2
13	Swelling clays encountered	2	2	4	Minimise distance drilled in any swelling clays identified in ground investigations	1	2	2
					Trained mud engineer to tailor drilling fluids to conditions	1	2	2
					Shale inhibitor additives in drilling fluid	1	2	2
					Gypsum based drilling fluid	1	2	2

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
14	HDD collision with sea defence foundations	2	2	4	Accurate survey of known structures and examination of records to identify previous structures that are no longer visible	1	2	2
					Acquire records from relevant authorities on the structures, particularly with regard to foundation and piling depths	1	2	2
					HDD design to allow for accuracy of guidance equipment in design distance from structures	1	2	2
					If encountered, trip pilot drill back and drill a sidetrack around the obstacle	1	2	2
15	Site works or HDD entry encounters Unexploded Ordnance	1	3	6	Commission a UXO specialist to undertake a desk study and any further recommended work	1	2	2
					UXO specialist to advise on precautions and any safe working methods required	1	2	2
					All excavations to be undertaken under a permit to dig system	1	2	2
					Suspected device is to be left in position, and UXO procedures followed.	1	2	2
16	Drilling stopped due to nuisance noise / lighting to neighbouring residences	3	2	6	Placement of topsoil stockpiles, office cabins etc as shielding	2	2	4
					Engines etc enclosed in silencing units	2	2	4
					Pre-construction baseline noise monitoring & mitigation planning	2	2	4
					Installation of dedicated engineered sound & light barriers	1	2	2
17	Fluid loss into and contamination of chalk aquifer	1	3	3	Ground Investigations to identify position of chalk and design to ensure sufficient elevation above the top of the chalk	1	2	2
					If small voids / losses are encountered attempt to seal with stop loss additives or grout	1	2	2
					If the voids / losses are too large to seal, drill with water rather than drilling fluid	1	3	3
					Abandon pilot hole and drill a new pilot at higher elevation	1	1	1
18	Flooding from tidal surge	1	3	3	HDD site at a sufficient elevation above sea level	1	3	3

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
19	Entry point unacceptable due to Archaeological finds.	1	3	3	Early stage archaeology studies at proposed sites to minimise impact on programme and cost	1	3	3
					Begin excavation of entry pits in advance of rig positioning to allow for alternative location	1	2	2
20	Collapse of dry borehole above sea level	2	3	6	Selection of entry position with low elevation	2	1	2
					Excavation of areas prone to collapse	1	1	1
					Installation of support casing in affected zones	1	1	1
					Ground improvement (grouting / soil mixing) prior to works commencing	1	1	1
21	Settlement damage to coastal defences or other infrastructure	1	2	2	Design to maximise distance from sensitive structures	1	2	2
					Settlement modelling to quantify settlement risk	1	2	2
					Monitoring programme for sensitive structures covering pre to post construction period	1	2	2
					Post installation grouting of HDD annulus if predicted settlement is unacceptable	1	1	1
22	Drill encounters unexpected ground that is unfavourable to HDD	2	3	6	Thorough Ground Investigations programme including boreholes and geophysical investigations	1	3	3
					Employ mitigation measures for adverse ground (downhole motor drilling, grouting etc.)	1	2	2
					Trip back and side-track into favourable ground	1	1	1
					Trip out and re-drill new profile or new location	1	1	1
23	Permitting authorities do not allow drilling fluid losses to the sea	1	3	3	Early consultation with, and approval from, relevant permitting authorities	1	3	3
					Revert to short option HDD with engineered containment of fluids at exit	1	1	1

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
24	Rollover / tip over of mobile equipment or heavy haulage	1	3	3	Access roads to be suitable for HGV's and routes to be strictly followed by drivers	1	3	3
					Site area to be stable and level	1	3	3
					Site area ground works designed to accept expected equipment loads	1	3	3
					Drivers to check and secure load prior to moving vehicle	1	2	2
					Banksman to supervise moving plant in site compound	1	3	3
					Only tracked or 4WD vehicles to access beach	1	2	2
25	Traffic accidents during movements to or from site	2	3	6	Identification of safest route in Traffic Management Plan	2	3	6
					Access roads to be suitable for HGV's and routes to be strictly followed by drivers	1	3	3
					Site deliveries to be restricted to daylight hours	2	3	6
					Adoption of high standards of driver competency and Drug & Alcohol policy	1	3	3
26	High vehicles coming into contact with overhead lines (OHL's)	1	3	3	Traffic Management Plan to identify route avoiding OHL's	1	3	3
					Any OHL's on access track to be identified by goal posts	1	3	3
					High loads to be met at access points and escorted under OHL's	1	3	3
27	Working at height (HDD rig operatives and mud system operatives)	2	3	6	Safe means of access to the working area to be provided.	1	3	3
					Ensure handrails are in place on equipment where access is required.	1	3	3
					Ensure compliance with the Work at Height. Regulations 2005	1	3	3
28	Failure, or tip over, of heavy lifting equipment	2	3	6	Mobilisation & demobilisation conducted by contract lift	1	3	3
					HDD contractor to use and follow their safe lift procedures for all lifts during HDD works	1	3	3
					HDD lifting equipment (hiabs, excavators, slings chains etc) to be certified and regularly checked	1	3	3

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
29	Buried services strike	2	3	6	Buried services search to be undertaken before work commences	1	3	3
					Underground services to be exposed as per HSG47.	1	3	3
					CAT scan to be carried out prior to excavation.	1	3	3
					All excavations to be undertaken under a permit to dig	1	3	3
30	Tool up for drilling Activities – manual handling, slips trips falls	2	3	6	Use mechanical handling were possible	1	3	3
					All electrical equipment to be inspected and tagged prior to use	1	3	3
					Working area to be kept clean and clear of obstacles	1	3	3
					All spillages to be contained and spill kits to be available at all times	1	3	3
31	Drilling fluid mixing – manual handling, dust, contact with chemicals	2	2	4	COSHH sheets to issued and the correct PPE to be worn.	1	1	1
					Use mechanical handling where ever possible	1	2	2
					Correct working platforms to be installed at all times.	1	2	2
					Dust masks to be used.	1	1	1
32	Open excavations	2	3	6	All excavations are to be fenced and signed to prevent unauthorised entry.	1	3	3
					Deep excavations to be suitably battered, stepped or supported with fixed ingress and egress points	1	2	2
					All excavations to be undertaken under a permit to dig system	1	3	3
33	Damage to existing offshore cables or pipelines during HDD operations	2	3	6	Identify position and depth of pipelines and cables	1	3	3
					Ensure suitable separation between HDD's and existing infrastructure	1	3	3
					Ensure sufficient stand-off between offshore vessels, including anchor points, and existing infrastructure	1	3	3
					Use of suitable HDD guidance system with accuracy to avoid any risk of misalignment.	1	3	3

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
34	General drilling operations – noise, dust, rotary equipment, moving plant	2	3	6	Signage denoting PPE required and hazard areas	1	3	3
					Site inductions, sign ins, tool box talks, and permit to work systems in place and adhered to	1	3	3
					Only experienced and competent operators to be used (CSCS scheme or equivalent).	1	3	3
					Hearing protection to be issued to all personnel when required and worn in designated areas	1	3	3
					Dust suppression to be employed when required.	1	3	3
					No loose clothing to be worn near rotating equipment. Rig operatives to wear coveralls.	1	3	3
					Emergency stop buttons to be fitted in accessible positions	1	3	3
					All hoses to be secured, gauges to be inspected prior to use.	1	3	3

12. SPECIFIC GEOTECHNICAL AND HDD RISKS

12.1. Ground Collapse

For the Happisburgh site the risk of ground collapse can be separated into four separate scenarios:

- Weak or very loose sediments in a borehole supported by drilling fluid
- Running / Blowing / Live Sands
- Weak or loose sediments in a borehole unsupported by drilling fluid
- Reactivation of historic large-scale subsidence feature

12.1.1 Weak or Very Loose Sediments in a Fluid Filled Borehole

The first risk is only likely to occur close to the exit point because the existing ground investigation boreholes indicate that ground strength below mean sea level along the designs is good. At exit any fallen material will be fluidised and removed by the reamer preceding the duct during installation.

12.1.2 Blowing / Running / Live Sands

The second scenario of blowing sands is discussed in detail in Section 4.2.3. It describes the situation where, generally fine, sands are transported into the borehole because the fluid in the sand layer is at a higher pressure than the fluid in the borehole. In cable percussion ground investigation drilling this process can be magnified because the plunging effect of the drilling and sampling tool creates a reduced pressure as it is lifted from the hole. In HDD drilling blowing sands are almost always contained in situ by the high viscosity and pressure of the drilling fluid.

The exception where HDD can have difficulty in containing blowing sands is where they are within artesian aquifers. Artesian aquifers are where the groundwater pressure within the strata causes the groundwater to flow to the surface of its own accord. Artesian pressures are not noted in any of the boreholes examined in this study and they are not expected given the design elevations for the HDD's.

12.1.3 Weak or Loose Sediments in a Dry Borehole

The third scenario is borehole collapse in parts of the HDD above sea level that are unsupported by drilling fluid is discussed in detail in Section 3.1. When the drill exits on the seabed the drilling fluid will equilibrate to the sea level. If the entry elevation is significantly higher than the sea level the result is a length of borehole at the entry point that is dry and therefore unsupported. This causes a significant increase in risk of ground collapse into the borehole, particularly in weak sediments. The risk increases with increasing borehole diameter because arch support in the ground is reduced.

At Happisburgh the risk is in the initial 23m to 46m of borehole in the silty, slightly gravelly, sand. If collapse is problematic, engineered mitigated is likely to use the installation of temporary steel casing over this length.

Ground investigations might give confidence that the silty gravelly sand is of sufficient strength to justify drilling without any mitigation methods and make provision to mitigate if ground collapse proves to be a problem. In most cases where HDD's encounter roof collapse within 20m of entry the duct is successfully pulled because the reamer and drilling fluid liquefies the fallen material.

12.1.4 Reactivation of the historic subsidence feature

The fourth scenario is that of reactivation of the historic subsidence zone discussed in Section 4.3. Reactivation might be caused by excessive water abstraction from the chalk aquifer or, much less likely, loss of drilling fluid causing lubrication and remobilisation of subsidence.

The evidence indicates that the structure has not been active over the past 70 years and that it is probably significantly older. While the risk of reactivation is thought to be very low the consequences of reactivation are high because they could affect a significant length of the borehole, perhaps 70m, and could continue to affect the installed cable.

In the event of reactivation, or elevated risk of reactivation, there is probably sufficient room within the cable corridor to locate the 12 HVAC ducts on the northwest side of the feature. Relocation would allow the feature to expand by 50m at its margin before it would affect the nearest duct.

If reactivation occurred after installation of the duct and subsidence was on the scale of 5m vertical with 30 degree tilting at the margin (as seen in the cliff exposures) duct extension could be in the order of 1.2m. This scale of extension could be accommodated by viscoelastic stretch in the duct, normal practice during pull-in is to allow for 3%-5% stretch in the duct to recover within 24 hours of pull in. However, there could be a risk of ovalisation or buckling of the HDPE at the inflection points of the settlement; this could affect the ability to remove and replace the installed cable.

The 1.2m extension in the duct would also need to be accommodated in the cable. The potential impact on the cable is beyond the expertise of the author but presumably would depend on how the cable is fixed at either end, whether provision is made for bights or similar, and the length of extension that might be accommodated within the cable.

Further investigation into the risk of reactivation of the feature by experts in subsidence is recommended. The Environment Agency holds LIDAR data taken at intervals since 1999 that might be assessed to gain further confidence that the area has been inactive since 1946 or earlier. The data is available in formats for GIS; a link to the data is provided in the References, Section 16.

12.2. Evaluation of HDD impact on cliff stability

12.2.1 Settlement above the HDD

Research into the stability of HDD boreholes has been conducted by Ariaratnam & Beljan (2005). A series of test HDD installed 100m, 200mm and 300mm ducts in sand and clay that were then excavated at varying periods from 1 day to 1 year. The study found that the integrity of the annular space was maintained with little evidence of voids and the strength properties increased over time through apparent consolidation, or equalization, with the native soil.

A photograph of the excavated 200mm duct from the study is shown in Figure 32. The sand drilled in the test installation is of similar grain size and density to the Happisburgh Formation and upper sections of the Crag. The study indicates that where the HDD is supported by drilling fluid, those sections where the depth of the HDD is below Mean Sea Level, the HDD is expected to remain stable. The section of HDD below mean sea level extends from 90m inland of the present cliff line to the exit point. The position 90m inland is equivalent to the Shoreline Management Plan predicted 2055 cliff position, so no adverse effect from the HDD on the cliffs is expected in the next 38 years.

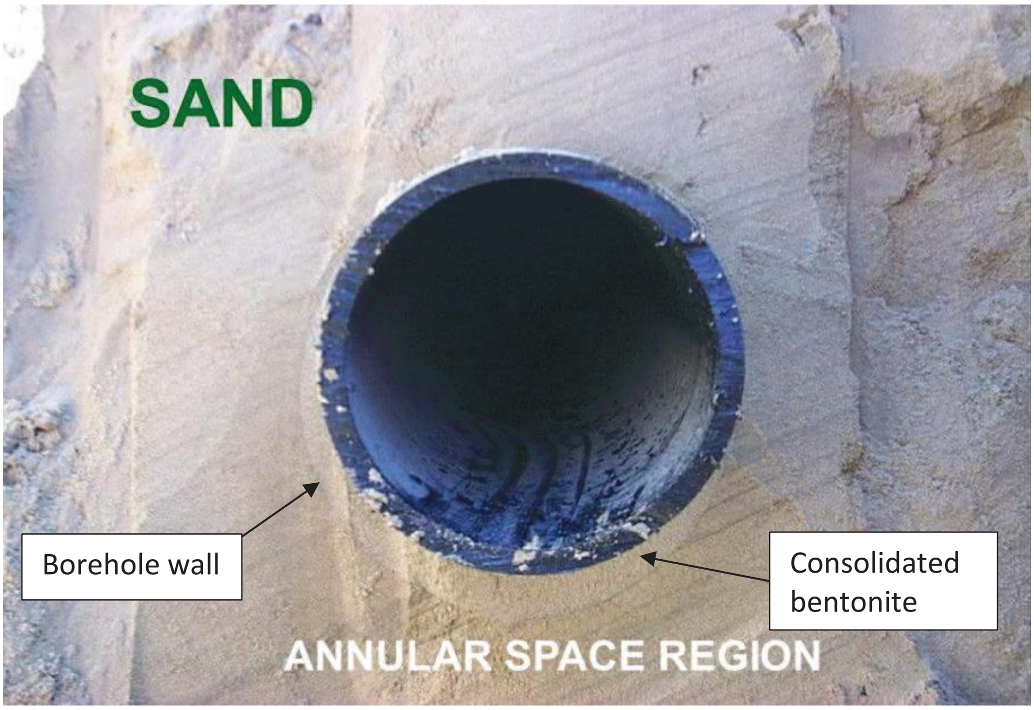


Figure 32. HDD installed 200mm diameter duct excavated 1 year after installation. Ariaratnam & Beljan (2005).

Although settlement above the HDD is not expected in these ground conditions, as a further check, settlement calculations have been undertaken (Figure 33 and Figure 34). The calculations assume that 10% of the annular space between the duct and the HDD borehole collapses. The calculations predict a maximum settlement at the base of the existing cliff of 2.1mm for the short HDD's exiting on the beach and 1.0mm for the long HDD's. This amount of settlement is equivalent to the grain size of sand and is unlikely to develop due; soil arching will develop before the settlement progresses to the base of the cliff.

To give an indication of the scale and position of the HDD's and ducts relative to the existing cliff line, and end view has been drawn for the south eastern half of the HVAC HDD's. The end view in Drawing No 20171201RA-C/03 (Appendix A) is at equal horizontal and vertical scale.

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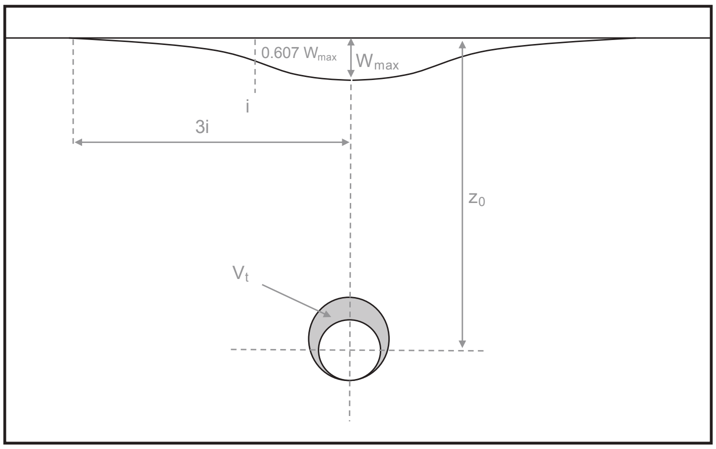
HDD SURFACE SETTLEMENT CALCULATION - LONG TERM SETTLEMENT

Estimates surface settlement trough based on gaussian equations (U of B notes)
Assumes volume loss at surface = volume loss in bore, $V_s = V_t$
Indicates absolute maximum long term settlement, ususally developed over a period of years
Assumes no support from bentonite.
Soil arching / bridging assumed to be non existent.

Client: Vattenfall
Project: Vanguard & Boreas - Short (170m) HDD's
Date: 26th February 2018

Soil type		sand
Pipe depth below surface, z_0	7.9	metres
Final ream diameter	660	mm
Duct OD	500	mm
Annular bentonite volume	0.146	m^3 / m length
Assumed bentonite shrinkage	10	%
Long term collapse volume, V	0.015	m^3 / m length
Inflection point, i	2.8	metres
Trough width	16.6	metres
W_{max}	2.1	mm

Settlement at any point		
Distance from centreline, x	3.0	metres
Settlement, W, at x	1.2	mm



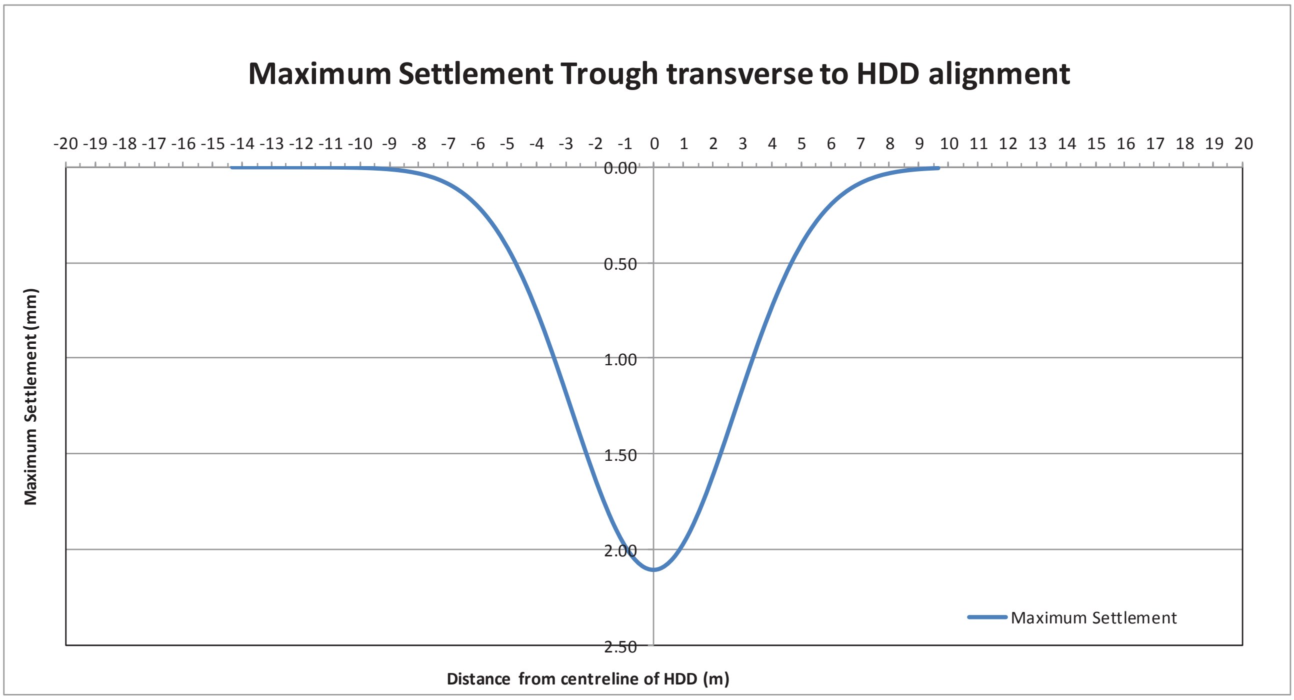


Figure 33. Settlement calculations for the short HDD's assuming 10% loss of annular volume progressing to the level of the base of the existing cliffs.

Riggall & Associates

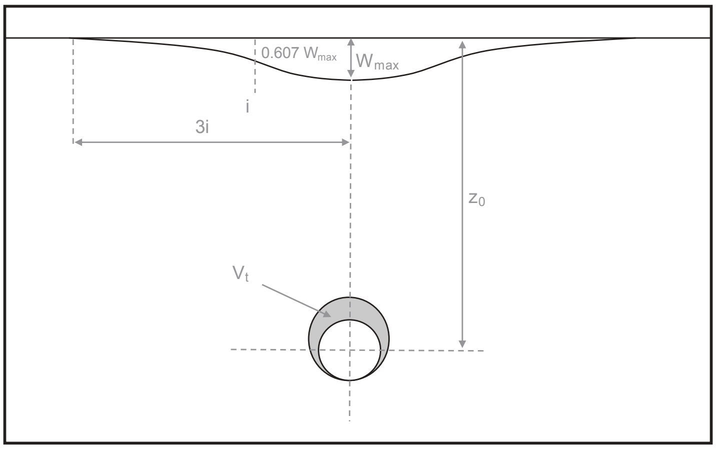
HDD SURFACE SETTLEMENT CALCULATION - LONG TERM SETTLEMENT

Estimates surface settlement trough based on gaussian equations (U of B notes)
Assumes volume loss at surface = volume loss in bore, $V_s = V_t$
Indicates absolute maximum long term settlement, ususally developed over a period of years
Assumes no support from bentonite.
Soil arching / bridging assumed to be non existent.

Client: Vattenfall
Project: Vanguard & Boreas - Long (690m) HDD's
Date: 26th February 2018

Soil type		sand
Pipe depth below surface, z_0	16.4	metres
Final ream diameter	660	mm
Duct OD	500	mm
Annular bentonite volume	0.146	m^3 / m length
Assumed bentonite shrinkage	10	%
Long term collapse volume, V	0.015	m^3 / m length
Inflection point, i	5.7	metres
Trough width	34.4	metres
W_{max}	1.0	mm

Settlement at any point		
Distance from centreline, x	3.0	metres
Settlement, W, at x	0.9	mm



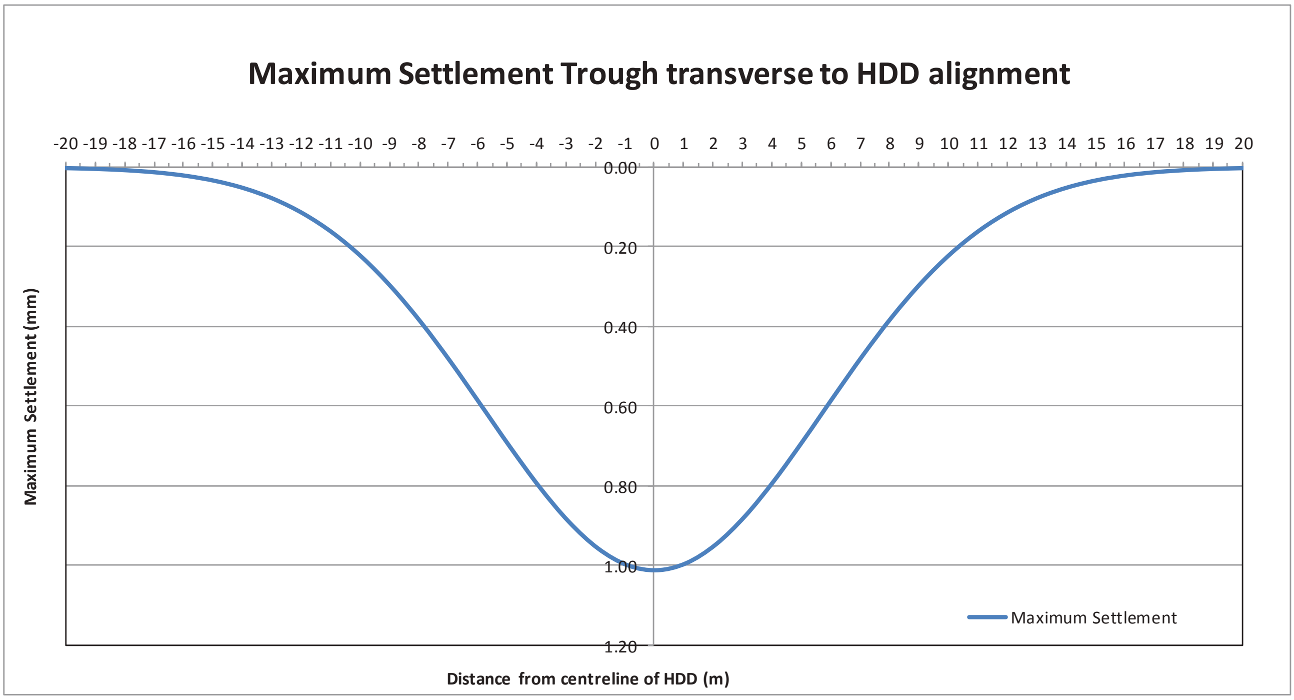


Figure 34. Settlement calculations for the long HDD's assuming 10% loss of annular volume progressing to the level of the base of the existing cliffs.

12.2.2 Vibration from the HDD

Vibration from the HDD is highly unlikely to affect the coastal cliffs. The drill itself can only be felt when it is less than 3m depth below surface and within a few metres of the drill line. There have been very few studies on vibration from HDD, however a Ground Vibration Monitoring Survey was undertaken during a HDD beneath the River Wye. The River Wye Vibration Monitoring equipment was positioned only 3m from the entry point. The level of vibration was well below DIN 4150 Maximum Vibration Level for the entire time and apart from thirteen readings the vibration was below the guidelines for sensitive structures.

The most vibration generated on a HDD site is always when the excavator tracks around the site. The site is located 125m inland form the coastal cliffs. HDD construction activities are not expected to generate less vibration at the cliffs than would be caused by ploughing of the fields or waves crashing on the shoreline.

12.3. Drilling Fluid Breakout and Losses

There are five distinct scenarios for when drilling fluid might be or will be lost to the surface or the sea for the landfalls.

12.3.1 Loss to Surface

Surface breakout most commonly occurs within the first 30m from entry and a competent contractor will avoid this on 90% of jobs. The HDD contractor will have a person walking the drill alignment checking for breakout. If detected the drilling is stopped immediately and the spill contained and removed.

It is good practice to have a stock of ready filled sandbags on site to contain a breakout if it occurs and a small pump with flexible hose to pump the bentonite back to the exit pit. At Happisburgh, given that the first 30m will be through agricultural fields, mitigation might take the form of digging a sump and bunding around any breakout with the site excavator. Breakouts that do occur are usually constrained to an area 3m x 3m and fluid depth of 0.2m giving a fluid volume of 1.8 m^3.

12.3.2 Loss to Voids

Loss of fluid to surrounding ground does not normally occur in HDD because the bentonite fluid is of high viscosity (an analogy is that it has a viscosity similar to mayonnaise) and seals the wall of the borehole. However, when drilling in ground with high permeability (e.g. peat) or voids (e.g. chalk) drilling fluid can be lost to the ground. The only real possibility of this occurring at Happisburgh is if the HDD drilled into the underlying chalk and encountered aquifers. This is a very low risk for this project based on the available ground information. Good ground investigations and good design are the main tools in mitigating this risk for the project.

If fluid is lost to the ground the mudman will quickly identify the losses because of the falling fluid levels within their mud tanks. Generally, the mudman will identify any losses greater than $2m^3$ in volume. Pumping will then be stopped and action taken to seal the area of loss; usually with stop-loss additives but in extreme cases, such as karst limestone, pumping in cementitious grout might be required.

The BGS borehole records of water bores completed in the surrounding area show that all were extracting from water from the chalk. Based on the available ground information, the HDD design will be between 14m (for a 1000m length drill) and 22m (170m length drill) above the level of the chalk and loss of drilling fluid to the chalk is highly unlikely.

In the unlikely event that drilling fluid was lost to the chalk aquifer, there is a low chance of it being drawn into abstraction bores. The chalk aquifers are recharged from the west and southwest where the chalk outcrops at surface. The strata dips to the northeast through the area and the groundwater flow is expected to also be in this direction.

All licensed abstraction points within a 5km radius are for agricultural use. The nearest abstraction point is 1.5km to the west where HBS Farms have a licence to abstract a maximum of 660m^3 daily. The worst-case scenario for drilling fluid losses is that losses are not noticed until the active tank is drained, a volume of approximately 20m^3. This volume of drilling fluid is unlikely be drawn to the nearest bore because of its greater density and higher viscosity than groundwater. If it was drawn into the bore it would be highly diluted, resulting in discolouration with no toxic effect; bentonite is a naturally occurring clay.

12.3.3 Loss on Exit

When the bit enters the sea the length of borehole above sea level will drain into the sea. The losses for all options at Happisburgh will be approximately 25 m^3 assuming a 26” (660mm) borehole and 50m length above sea level. For the short HDD’s this volume can mostly be captured at the exit point on the beach by bunding the exit area. For the long HDD’s this volume will be lost to the sea.

12.3.4 Loss During Final Pull Reaming

Normal practice for landfalls is to drill a pilot hole to around 30m to 50m before the planned exit point. The hole is then forward reamed to the end of the pilot hole and tripped out. The pilot bit is tripped in and drills out the final 30m to exit.

The last section of hole then needs to be opened up to final diameter by pull reaming from the exit point towards the section of hole that has already been enlarged by forward reaming. The length of pull reaming on this project is expected to be 30m with 50m as a worst case. During the pull reaming drilling fluid will need to be pumped to remove cuttings from the hole and this will exit into the sea.

For the long HDD’s the worst-case scenario is that the ground dictates that 3 different sized pull reams are necessary. If they progress at 1 minute per metre of drilling advance and the fluid pumping rate is 800 litres/minute then the losses to the sea will be 120m^3.

For the short HDD’s there is the possibility of constructing a temporary structure (e.g. a sheet piled coffer dam) around the exit point to prevent the fluid being dispersed as the tide rises above the exit point and transferring the fluid back to the entry pit for recycling.

12.3.5 Loss During Duct Installation

During installation there are two factors contributing to losses; fluid pumped through the reamer in front of the duct to ensure the hole is clean, and fluid displaced by the duct as it is pulled into the hole. For the long 700m HDD’s the worst-case scenario is an installation rate of 2 metres per minute for the 700m drilled borehole length. At a pumping rate of 500 litres per minute this would result in a pumped volume of 175m^3.

Assuming the initial 50m of borehole at entry is dry, the displacement volume for the 650m of fluid filled borehole by a 500mm duct is 128m^3.

The worst-case scenario of total volume lost during installation of the ducts on the long 700m HDD is therefore 303m^3.

For the short HDD's there is the opportunity to capture fluid at the exit point as discussed in Section 12.3.4 above.

12.3.6 Environmental impact of HDD fluid

The drilling fluid predominantly used in HDD is a mix of water and a naturally occurring swelling clay, bentonite. On occasions the chemical properties of the drilled soil or rock reduce the effectiveness of the drilling fluid. As a result, additives such as natural xanthum gum and gypsum are sometimes added to improve the properties of the fluid, however they are unlikely to be required for this project.

Bentonite drilling fluid is non-toxic however if sufficient quantity enters a freshwater watercourse it can potentially settle on the bottom, smothering benthic flora and affecting faunal feeding and breeding sites. In saltwater environments the smothering affect is less problematic because seawater degrades the bentonite fluid, causing it to flocculate and allowing rapid dispersal.

On some landfall HDD's a proprietary drilling fluid called Purebore is used for the conventional reaming. Purebore is CEFAS registered and biodegradable. In environments with strong water currents and sediment loading the release of bentonite fluid might not be of environmental significance because it is a naturally occurring clay and breaks down (flocculates) in saline water.

12.3.7 Sediment Volumes within the Fluid

The volumes provided in the sections above are for the fluid itself which will carry a varying solids content depending on the phase of the operations. The phase with releasing the greatest volume of sediment is the loss during final pull reaming. Pull reaming the final 30-40m of the HDD is estimated to release 120m^3 of fluid, however the solids volume will be equivalent to the volume of the final 40m of HDD bore, approximately 14m^3. The environmental impact of this volume needs to be assessed in relation to the volumes transported by natural processes in the area, but it is not expected to be significant given the high seafloor sediment mobility along this stretch of coastline.

12.4. Pollution from Spills

A Medium-High groundwater vulnerability zone with a Secondary-A Aquifer in the superficial deposits (Happisburgh Glacigenic Formation and Norwich Crag) overlying a Principal Aquifer in the Upper Chalk. The aquifers in the Crag and Chalk are most probably hydraulically connected. Consequently, any spills at surface have the potential to enter the groundwater supply.

The potential materials that might be spilt on site are diesel fuel, engine oils, hydraulic oils, and wastewater from toilet facilities. Fuel storage tanks and all oils will be stored with bunding in accordance with Oil Storage Regulations 2001. Toilet facilities will contain all waste for removal from site to wastewater treatment works.

Emergency spill kits will be provided in key locations around the site. MSDS sheets will be held on site for all chemicals used.

The site working area will be prepared on a geotextile base with site runoff directed to one or more settlement ponds with silt fencing on overflow points.

12.5. Settlement above sections of the HDD drilled above MSL

The stabilising effect of the bentonite drilling fluid, combined with the ground strength determined from geotechnical investigations, indicates that settlement in sections of the HDD drilled below Mean Sea Level (MSL) is unlikely. The risk of settlement therefore resides in the initial 45m of borehole from entry point to a depth equivalent to MSL.

Settlement above the initial 45m of the HDD could occur if the roof of the HDD collapses, either during drilling, or following installation of the duct. The void created then migrates upwards and outwards towards the surface, resulting in a settlement trough at the surface.

Settlement caused by HDD's is normally only problematic when shallow (less than 5m) and large diameter (greater than 500mm) HDD's are drilled close to sensitive structures (railways, residences etc). While not expected, settlement in the fields in front of the HDD entry points is likely to be of a low level (centimetres) and unlikely to impact on the future use of the fields.

12.6. Water incursion along the installed HDD

There is a very low risk of surface or groundwater utilising the HDD as a flow route during or after installation of the duct. The bentonite drilling fluid seals the annulus of the borehole and consolidates over time as discussed in Section 12.2 and illustrated in Figure 32.

There is the potential for the bentonite fluid in the final few metres of the HDD before exit being degraded by seawater, because standard bentonite drilling fluid flocculates when it comes into contact with seawater. This could result in localised collapse of sediment around the duct over these final few metres. However, it is more likely that following installation tidal currents will cause accumulation of sediment at the duct exit, minimising the volume of flocculated fluid that can be washed from the hole and buffering the remaining fluid from any further degradation.

13. INDICATIVE PROGRAMME & COST

Indicative programmes for the HDD landfalls options are provided in Table 7 to Table 10 below. The programmes have been calculated for the four options as follows:

- Short HDD's exiting on the beach for 4 No. of HVDC cables
- Long HDD's exiting beyond 5.5m water depth for 4 No. of HVDC cables
- Short HDD's exiting on the beach for 12 No. of HVAC cables
- Long HDD's exiting beyond 5.5m water depth for 12 No. of HVAC cables

The programmes assume 12 hour working. The short HDD options are likely to be drilled with 12 hour per day working. The long HDD options are more likely to involve 24 hour per day work activities. The 24/7 total shown includes 24 hour working for drilling activities and 12 hour working for pullback, site works, mobilisation and demobilisation.

For the HVDC option the contractor is likely to use a single HDD rig for the four landfalls. A second rig can be brought in if the programme requires it.

For the HVAC option of 12 HDD's the contractor is likely to utilise 2 drilling rigs to shorten the programme. Using 3 rigs is possible but most contractors would not have the third rig available and would have to subcontract another HDD company. If the projects are completed separately it is likely that 2 rigs would be used to drill 6 landfalls to shorten the programme.

Cost estimates have been prepared for the case of a single HDD and are shown in Table 6 below. Two estimate methods have been used, by HDD length and diameter, and by programme shifts. The two methods broadly agree for the short HDD's, however for the long HDD's the metre based pricing is higher than the programme based pricing. This is because the silty sand should drill much faster than most other locations in the UK that tend to be drilled more in clays.

The pricing is indicative only, the cost of HDD drilling for the long options is particularly susceptible to market conditions due to the smaller pool of capable contractors. If HDD contractors' order books are full at the time of tendering there will be a premium placed on the tender prices.

VATTENFALL HAPPISBURGH - INDICATIVE PRICE RANGE FOR A SINGLE HDD LANDFALL										
Cable	Long / Short	Length (m)	Duct O.D. (inch)	Programme No. 12 hr Shifts	PRICING BY METERAGE AND DIAMETER			PRICING BY PROGRAMME		
					Lower	Expected	Upper	Lower	Expected	Upper
HVAC	Short	170	20	9	£ 68,000	£ 136,000	£ 204,000	£ 75,333	£ 113,000	£ 150,667
HVAC	Long	700	20	32	£ 700,000	£ 980,000	£ 1,260,000	£ 569,464	£ 759,286	£ 949,107
HVDC	Short	170	20	9	£ 68,000	£ 136,000	£ 204,000	£ 75,333	£ 113,000	£ 150,667
HVDC	Long	700	20	32	£ 700,000	£ 980,000	£ 1,260,000	£ 569,464	£ 759,286	£ 949,107
Notes: The costing is only for the HDD works and does not include site groundworks and access, duct purchase or fabrications, or the cost of marine works to facilitate reaming and duct installation. Pricing includes HDD Contractors profit margin but does not include a margin for any Principal Contractor										

Table 6. Indicative costs for a single landfall HDD at each location for long and short options

INDICATIVE PROGRAMME FOR HDD WORKS AT HAPPISBURGH, LONG AND SHORT OPTIONS												
ACTIVITY	Happisburgh - HVAC Short HDD's											
	HDD #1	HDD#2	HDD#3	HDD#4	HDD#5	HDD#6	HDD#7	HDD#8	HDD#9	HDD#10	HDD#11	HDD#12
	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts
Site establishment works	15.0	-	-	-	-	-	-	-	-	-	-	-
Mobilisation & Setup	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Pilot hole drilling: 0 - 170m	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Forward ream 16": 170 - 170m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forward ream 22": 170 - 170m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forward ream 26": 170 - 170m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pilot hole drilling: 170 - 170m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Beach works	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Back ream 16": 0 - 170m	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Back ream 22": 0 - 170m	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Back ream 26": 0 - 170m	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Cleaning pass	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pullback of pipeline	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Demobilisation	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Site reinstatement works	-	-	-	-	-	-	-	-	-	-	-	15.0
TOTAL 12 hr Shifts	26.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	24.4
Total 12hr Shifts for 12 No. HDD's	**145**											
Total weeks, day working, 7 day weeks	**20.7**											
Total weeks, 24/7 working	**15.2**											

Notes: Time for duct preparation and offshore works are not included as they will be concurrent with HDD works.
Assumes a single HDD rig. Programme can be reduced by using multiple rigs.
No allowance for weather delays to offshore works has been made.

Table 7. Indicative programmes of works for the HVAC short (170m) option assuming 12 hr shifts.

INDICATIVE PROGRAMME FOR HDD WORKS AT HAPPISBURGH												
ACTIVITY	Happisburgh - HVAC Long 700m HDD's											
	HDD #1	HDD#2	HDD#3	HDD#4	HDD#5	HDD#6	HDD#7	HDD#8	HDD#9	HDD#10	HDD#11	HDD#12
	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts
Site establishment works	15.0	-	-	-	-	-	-	-	-	-	-	-
Mobilisation & Setup	5.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Pilot hole drilling: 0 - 670m	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Forward ream 16": 0 - 660m	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Forward ream 22": 0 - 650m	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Forward ream 26": 0 - 640m	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Pilot hole drilling: 670 - 700m	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Barge works	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Back ream 16": 660 - 700m	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Back ream 22": 650 - 700m	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Back ream 26": 640 - 700m	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cleaning pass	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Pullback of pipeline	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Demobilisation	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Site reinstatement works	-	-	-	-	-	-	-	-	-	-	-	15.0
TOTAL 12 hr Shifts	48.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	46.6
Total 12hr Shifts for 12 No. HDD's	**412**											
Total weeks, day working, 7 day weeks	**58.8**											
Total weeks, 24/7 working	**36.8**											

Notes: Time for duct preparation and offshore works are not included as they will be concurrent with HDD works.
Assumes a single HDD rig. Programme can be reduced by using multiple rigs.
No allowance for weather delays to offshore works has been made.

Table 8. Indicative programmes of works for the HVAC long (700m) option assuming 12 hr shifts. Assumes no weather delay for offshore works.

INDICATIVE PROGRAMME FOR HDD WORKS AT HAPPISBURGH				
ACTIVITY	Happisburgh - HVDC Short HDD's			
	HDD #1	HDD#2	HDD#3	HDD#4
	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts
Site establishment works	15.0	-	-	-
Mobilisation & Setup	3.0	1.0	1.0	1.0
Pilot hole drilling: 0 - 170m	1.4	1.4	1.4	1.4
Forward ream 16": 170 - 170m	0.0	0.0	0.0	0.0
Forward ream 22": 170 - 170m	0.0	0.0	0.0	0.0
Forward ream 26": 170 - 170m	0.0	0.0	0.0	0.0
Pilot hole drilling: 170 - 170m	0.0	0.0	0.0	0.0
Beach works	0.3	0.3	0.3	0.3
Back ream 16": 0 - 170m	1.4	1.4	1.4	1.4
Back ream 22": 0 - 170m	1.4	1.4	1.4	1.4
Back ream 26": 0 - 170m	1.4	1.4	1.4	1.4
Cleaning pass	0.5	0.5	0.5	0.5
Pullback of pipeline	1.0	1.0	1.0	1.0
Demobilisation	1.0	1.0	1.0	1.0
Site reinstatement works	-	-	-	15.0
TOTAL 12 hr Shifts	26.4	9.4	9.4	24.4
Total 12hr Shifts for 12 No. HDD's	**70**			
Total weeks, day working, 7 day weeks	**10.0**			
Total weeks, 24/7 working	**8.1**			

Notes: Time for duct preparation and offshore works are not included as they will be concurrent with HDD
Assumes a single HDD rig. Programme can be reduced by using multiple rigs.
No allowance for weather delays to offshore works has been made.

Table 9. Indicative programmes of works for the HVDC short (170m) option assuming 12 hr shifts.

INDICATIVE PROGRAMME FOR HDD WORKS AT HAPPISBURGH				
ACTIVITY	Happisburgh - HVDC Long 700m HDD's			
	HDD #1	HDD#2	HDD#3	HDD#4
	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts
Site establishment works	15.0	-	-	-
Mobilisation & Setup	5.0	3.0	3.0	3.0
Pilot hole drilling: 0 - 670m	5.6	5.6	5.6	5.6
Forward ream 16": 0 - 660m	4.7	4.7	4.7	4.7
Forward ream 22": 0 - 650m	4.6	4.6	4.6	4.6
Forward ream 26": 0 - 640m	4.6	4.6	4.6	4.6
Pilot hole drilling: 670 - 700m	0.3	0.3	0.3	0.3
Barge works	3.0	3.0	3.0	3.0
Back ream 16": 660 - 700m	0.5	0.5	0.5	0.5
Back ream 22": 650 - 700m	0.6	0.6	0.6	0.6
Back ream 26": 640 - 700m	0.8	0.8	0.8	0.8
Cleaning pass	1.0	1.0	1.0	1.0
Pullback of pipeline	1.0	1.0	1.0	1.0
Demobilisation	2.0	2.0	2.0	2.0
Site reinstatement works	-	-	-	15.0
TOTAL 12 hr Shifts	48.6	31.6	31.6	46.6
Total 12hr Shifts for 12 No. HDD's	**159**			
Total weeks, day working, 7 day weeks	**22.6**			
Total weeks, 24/7 working	**15.3**			

Notes: Time for duct preparation and offshore works are not included as they will be concurrent with HDD works.
Assumes a single HDD rig. Programme can be reduced by using multiple rigs.
No allowance for weather delays to offshore works has been made.

Table 10. Indicative programmes of works for the HVDC long (700m) option assuming 12 hr shifts. Assumes no weather delay for offshore works.

14. SUMMARY AND CONCLUSIONS

14.1. Evaluation of Options

Four options have been considered for HDD cable landfalls at Happisburgh:

- Short HDD's exiting on the beach for 4 No. of HVDC cables
- Long HDD's exiting beyond 5.5m water depth for 4 No. of HVDC cables
- Short HDD's exiting on the beach for 12 No. of HVAC cables
- Long HDD's exiting beyond 5.5m water depth for 12 No. of HVAC cables

Each of the HDD options is technically possible; the ground conditions are very good and suited to relatively quick drilling and completion. The short HDD's will mostly be drilled in dense silty SAND and firm to stiff slightly silty gravelly CLAY. The long HDD's will be drilled predominantly in very dense silty SAND with some layers of gravelly SAND.

The main geotechnical risk is reactivation of a suspected ancient subsidence feature on the south-eastern side of the site (Section 4.3). Based on available information the feature is assessed as possibly having formed over 5000 years ago and appears to have been stable for at least the previous 70 years and probably unchanged for the last 130 years as a minimum.

Reactivation of the subsidence feature would probably require excessive drawdown of the water table in the chalk aquifer, thought to be very unlikely because of its status as a major aquifer with well managed abstraction. Another possibility for reactivation on a small scale in the sediments within the feature is from loss of drilling fluid to high permeability zones. This is thought to be highly unlikely based on the density of the sediments exposed in the coastal cliffs and the nature of drilling fluid to seal the annulus of the HDD bore.

There is sufficient room at the site to drill any of the four options, although the long HVAC has less scope for moving the position of drills to avoid adverse ground or archaeology, purely because of the number of drills.

Conceptual designs have been drawn for the short and long (700m) options and exit sites for 1000m long options have also been shown to aid evaluation of exit point suitability for cable vessels and cable pull in. The short designs exit in the intertidal area of the beach. The 700m length HDD's exit at -5.5m to -6.5m LAT, and the 1000m HDD's exit at approximately -9.5m LAT. The designs for HVAC are shown on Drawing No. 20171201RA-C/01 and the HVDC designs on Drawing No. 20171201RA-C/02 in Appendix A.

There are advantages and disadvantages to the various options and these are summarised in the table below. The long HVDC options has a significant disadvantage in terms of greatest duration and impact on the local community and HDD offshore cost.

The short options, particularly the HVAC short option, has potential for significant periods of closure of the beach to the public and significant weather delay risks for the 12 No cable float in.

OPTION	ADVANTAGES	DISADVANTAGES
HVAC Short	• Shorter programme than HVAC Long option • Lower non-completion risk than HVAC Long option • Day working only • Greater choice of HDD contractors than long options	• Considerable beach works duration with probable periods of beach closure to public. • More susceptible to weather delay on beach works and duct installation than HVDC short. • Requires suitable weather for 12 separate cable float in • Requires works to ensure remnant sea defences are removed • AC cable design likely to drive shallower design than HVDC with greater fluid breakout risk • Three times more traffic than HVDC
HVAC Long	• Probably avoids cable float-in, reducing risk of weather delay • Potential to extend to 1000m and increase the choice of cable vessels	• Less room to position HDD's if archaeology or subsidence structure is to be avoided • AC cable design likely to drive shallower design than HVDC with greater fluid breakout risk • Significant offshore costs for HDD works • Noise mitigation required for night working • Three times more traffic than HVDC • Greatest volume of drilling fluid release to sea (3x more than HVDC long)
HVDC Short	• Shortest HDD programme of all options • Plenty of scope to reposition for avoidance of archaeology or subsidence feature • Lowest Land footprint • Lowest non-completion risk • Greater choice of HDD contractors than long options • Least traffic movements	• Beach works with probable periods of beach closure • Cable float in with weather risks
HVDC Long	• Shorter HDD programme than HVAC long and similar to HVAC short • Plenty of scope to reposition for avoidance of archaeology or subsidence feature • Potential to extend to 1000m and increase the choice of cable vessels • Much reduced land footprint compared to HVAC options • DC cable probably allows deeper design for thermal reasons, providing greater protection about fluid breakout compared to HVAC long, particularly if considering 1000m drill • Probably avoids cable float-in, reducing risk of weather delay	• Longer HDD program than HVDC short • Costs for offshore HDD works that are not required for short options • Drilling fluid releases to sea

Table 11. Comparison of the advantages and disadvantages of the four HDD options

15. RECOMMENDATIONS

15.1. Option Selection

Apart from the implications of each HDD option on the overall projects cost, option selection will need to evaluate the HDD aspects discussed in this report with offshore considerations, onward cabling to the grid connection point, and the impact of the works on the local community.

It is recommended that the conceptual HDD designs are reviewed by cable engineers and offshore installation experts to reach the optimal technical and construction solution for the project. The conceptual designs provided are intended as a starting point for discussion and refinement. The burial depth of the cable will need to balance HDD risks such as drilling fluid breakout with cable design driven by thermal losses. The burial depth and cable design usually requires an iterative process between the two disciplines to achieve a suitable design solution.

15.2. Further Information

For any future studies and designs the following information and data will be required:

- Preferred cable size and likely pulling length limit
- Maximum depth of cover for preferred cable
- Minimum separation distance between ducts
- Preference for HVAC or HVDC
- Preference for a short or long exit
- Preferences for exit depths on long HDD's
- LIDAR or topographical survey of the site
- If the Environment Agency have LIDAR taken from different years this data should be compared for any changes in the historic subsidence zone
- Bathymetric survey of the sites and confirmation of ODN to chart datum LAT conversions
- Further ground investigations (see Section 15.3)
- Details of design and foundation depths for sea defences.
- Design life of installations to determine position of HDD entry points
- Continued archaeological investigations
- An unexploded Ordnance Desk study should be commissioned from an UXO specialist to inform any UXO site investigations that might be required
- If information on sea defences are not available or known a geophysical method could be used to assess if any steel sheet piling is present
- Engage an expert on ground subsidence to assess the risk from the subsidence feature
- Cable engineers to assess the risks to cables from a subsidence event

15.3. Ground Investigations

Additional boreholes to test the subsidence feature and deeper sections of the Crag are required. A marine survey is required for the section of HDD from the beach beyond exit.

If time permits a phased approach is recommended for the ground investigations to improve the quality of the information. It is suggested that Phase 1 would be land based boreholes, Phase 2 marine survey and Phase 3 marine boreholes. If deemed necessary, land based geophysics could be added as Phase 4.

When any of the ground investigation reports is complete it should be reviewed by a HDD specialist for impact on the HDD design options.

The risk of unexploded ordnance should be assessed prior to ground investigations to determine any requirement for UXO searches prior to boring and/or magnetometer readings when boring.

15.3.1 Land Boreholes

The land boreholes are expected to be drilled by cable percussion methods and potentially with rotary coring if the ground proves difficult for cable percussion. All boreholes are to be backfilled with bentonite chippings to ensure they do not provide a route for drilling fluid breakout during HDD drilling.

15.3.2 In Situ and Laboratory Testing

During cable percussion drilling regular Standard Penetration Tests (SPT's) should be performed and undisturbed samples taken wherever possible (generally in cohesive). Bulk samples are expected to be regularly taken in the granular soil. Any rotary core drilling will supply U100 core, some of which will be sent for laboratory testing.

Apart from SPT's in situ testing is only likely to be falling head permeability tests if significant aquifers are encountered, particularly in chalk.

The laboratory tests in Table 12 are to be undertaken where the quality of the samples allows. Thermal conductivity testing is also likely to be required. Cable specialists should advice on the number and location of samples to be tested.

Cohesive Soils	**Granular Soils**	**Core Samples**
Moisture Content	Particle Size Distribution	Point Load
Atterberg limits	Bulk density	UCS
Density		
Undrained Triaxial testing		

Table 12. Suggested laboratory testing for borehole samples

15.3.3 Marine Geophysics & Bathymetry

The offshore geophysical survey is likely to be a seismic survey using a towed boomer source; however, the geophysical survey contractor will advise on the most suitable technique for the expected geology and bottom profile.

The primary aim of the geophysical survey is to identify the base of Holocene sediments, and the boundary between the basal tills of the Happisburgh Glacigenic Formation and the silty sands of the underlying Crag. Ideally the survey should attempt to identify reflectors down to 20m depth below the seafloor, however it is recognised that geological conditions do not always permit this.

The survey should attempt to chart as close to the shoreline as possible, but this will be determined by vessel, tidal, and weather conditions during the survey.

15.3.4 Marine Boreholes

It is suggested that the Marine boreholes are drilled after the land boreholes and marine survey have been completed and the geology reviewed. This will allow better targeting and positioning of the marine boreholes.

If the long HDD option is to be considered the marine boreholes are essential in reducing the risk of unplanned breakout to the sea. They are likely to be drilled from a jack up platform and will probably be cable percussion drilled to effectively sample the expected ground conditions.

Vibrocore samples near the expected exit points for the long HDD option would be useful in determining the thickness and nature of any loose sediment at the exit point.

15.4. Mitigating the Risk of Drilling Fluid Breakout

15.4.1 HDD Design

A suitable HDD design for the ground conditions is the most effective tool to reduce the risk of drilling fluid breakout. A preliminary HDD design for the chosen site/s should be drafted once the results from ground investigations (onshore and offshore), soil testing results, topographical and bathymetric surveys, and sea defence design information has all been received. The design will require input from cable engineers to ensure the depth of cover is suitable.

The preliminary design should then be assessed for the risk of breakout using hydrofracture modelling to allow refinement of the design. A review of drilling and installation forces can also be undertaken along with calculation of cable installation forces.

The hydrofracture modelling will also inform the risks associated with different downhole drilling assemblies and pilot hole diameters, allowing selection of suitable drilling techniques and drilling equipment.

15.4.2 HDD Drilling Procedure

A key component of avoiding breakout is effective removal of the cuttings from the borehole. If cuttings are not removed they form cuttings beds on the base of the borehole, decreasing the cross-sectional area of the borehole. This causes an increase in annular pressure and therefore increases the risk of breakout. Cuttings in the borehole also lead to increased drilling forces and can eventually cause equipment to be lost or stuck downhole.

A competent HDD contractor will be proactive in ensuring that cuttings are effectively removed and will spend additional time and effort to reduce the risk of both breakout and stuck equipment.

An additional tool that is recommended to assist in monitoring the state of the borehole is Downhole Annular Pressure Monitoring. Supplied as a standard add-on to the guidance equipment the tool measures the pressure in the borehole annulus in real-time. The actual value can be compared to limit values calculated from hydrofracture analysis to avoid damaging the ground surrounding the HDD during pilot hole drilling. By avoiding any over-pressuring of the surrounding ground the risk of surface breakout is greatly reduced.

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APPENDIX A

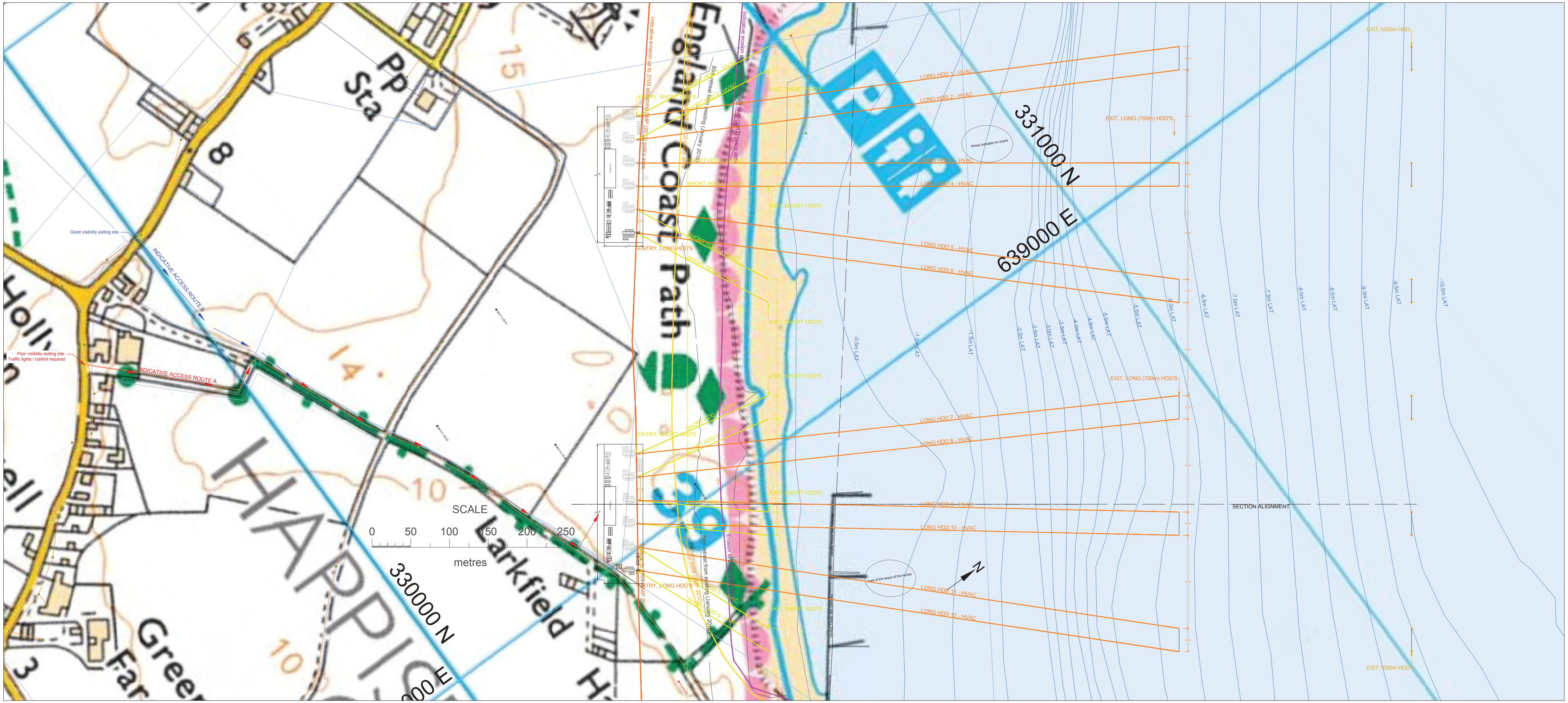
Drawings

Drawing No's:

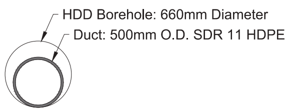
20171201RA-C/01 – Conceptual HDD Designs - HVAC Happisburgh

20171201RA-C/02 – Conceptual HDD Designs - HVDC Happisburgh

20171201RA-C/03 – End View of Conceptual HDD Designs - HVAC Happisburgh



PLAN VIEW



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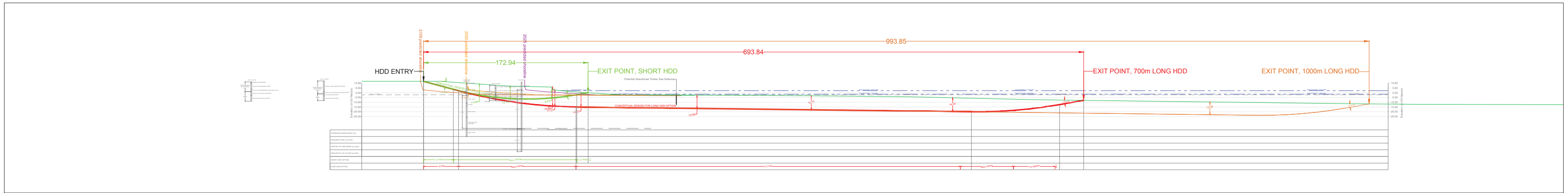

SECTION VIEW

NOTES

1. ALL DIMENSIONS, LEVELS AND CHAINAGES ARE IN METRES UNLESS OTHERWISE STATED. PROPOSED BOREHOLES ARE INDICATED BY YELLOW MARKERS.
2. LAND ELEVATIONS ESTIMATED FROM OS MASTERMAP1:25,000 MAPPING
3. LAT ESTIMATED AT -2.20 ODN FROM INTERPOLATION OF VALUES AT CROMER AND WINTERTON.
4. BATHYMETRY IS INDICATIVE ONLY AND REQUIRES A BATHYMETRIC SURVEY
5. GEOLOGY IS BASED ON INTERPRETATION OF AVAILABLE BGS BOREHOLE LOGS, BOREHOLE INFORMATION PROVIDED BY VATTENFALL AND MAPPING OF COASTAL EXPOSURES.

DO NOT SCALE

Rev	Date	Description	By
C	22/01/2018	Corrected spacing between ducts	TR
B	17/01/2018	Feasibility Report Rev00	TR
A	14/01/2018	Draft for discussion	TR

Client: VATTENFALL WIND POWER LTD

Scale	Drawn by	Date Drawn	Sheet Size
AS SHOWN	TR	14/01/2018	A1

Designed by	Checked by	Approved by	Date approved
TR			

Drawing Number: 20171201RA-C/01

Issue: A

Project Title: VANGUARD & BOREAS HDD FEASIBILITY STUDY

Drawing Title: CONCEPTUAL HDD DESIGNS - HVAC HAPPISBURGH

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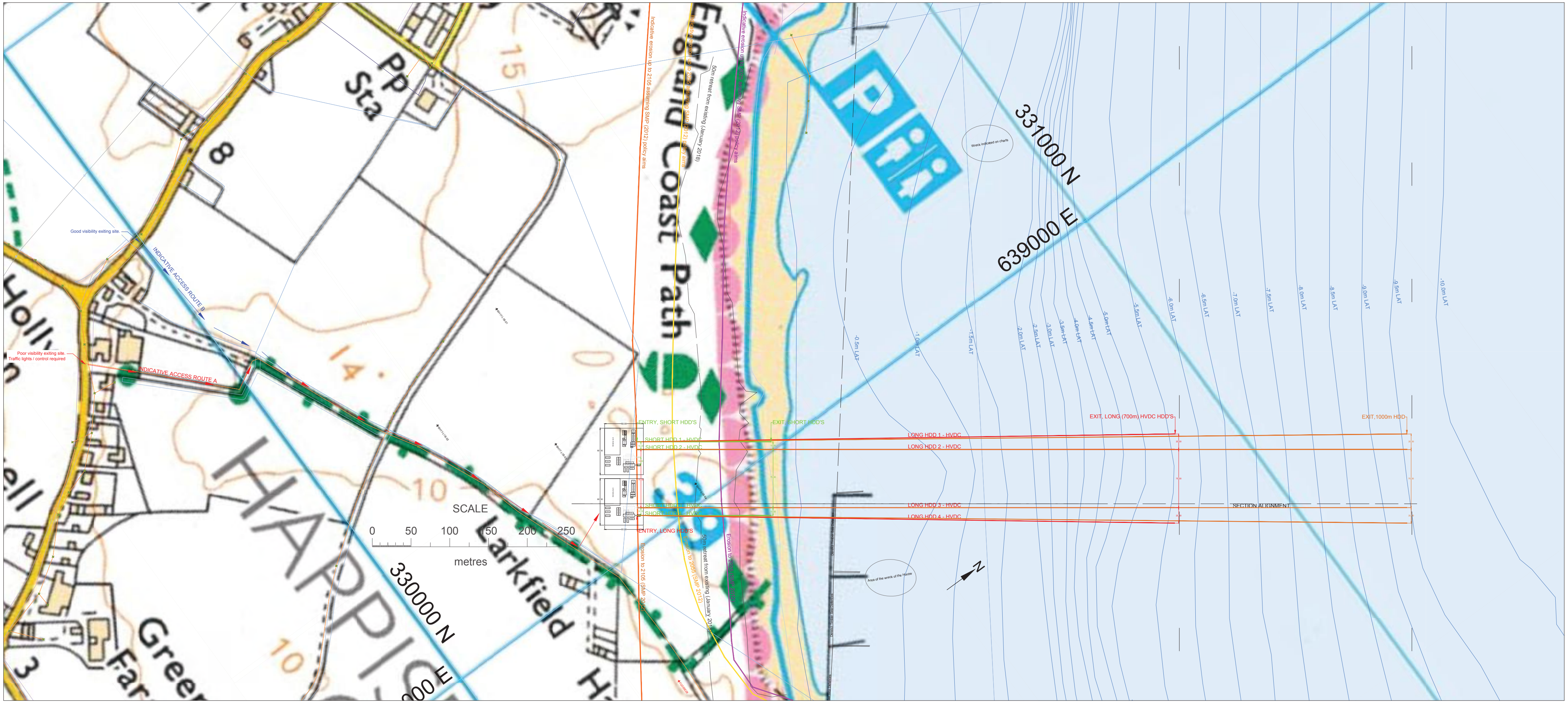

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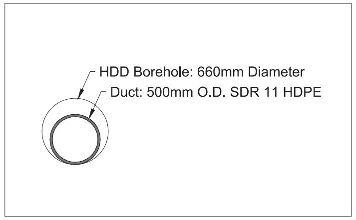

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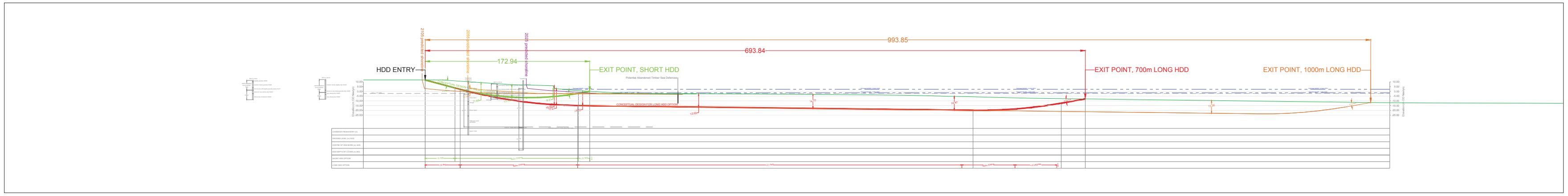

SECTION VIEW

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Rev	Date	Description	By
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B	17/01/2018	Feasibility Report Rev00	TR
A	14/01/2018	Draft for discussion	TR

Client: VATTENFALL WIND POWER LTD

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Designed by	Checked by	Approved by	Date approved
TR			

Drawing Number: 20171201RA-C/02

Issue: A

Project Title: VANGUARD & BOREAS HDD FEASIBILITY STUDY

Drawing Title: CONCEPTUAL HDD DESIGNS - HVDC HAPPISBURGH

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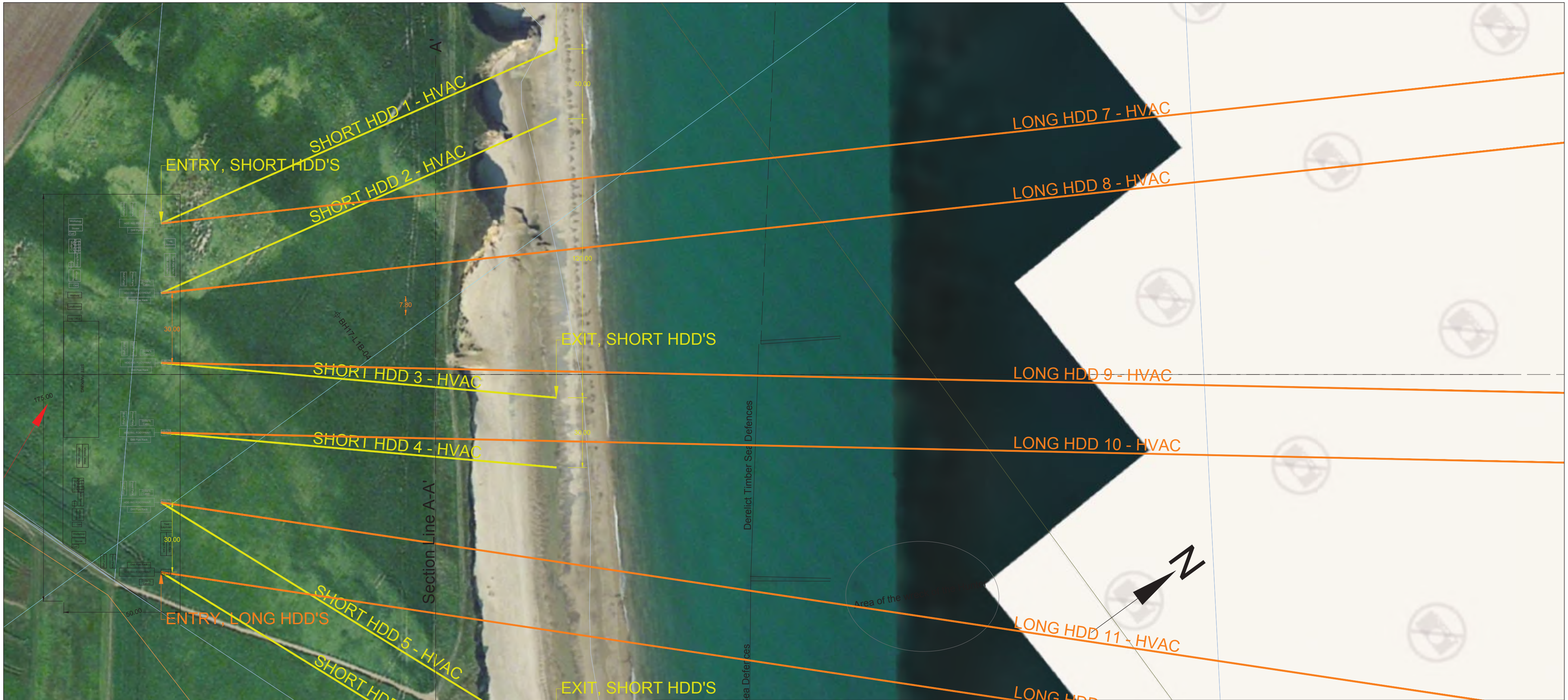

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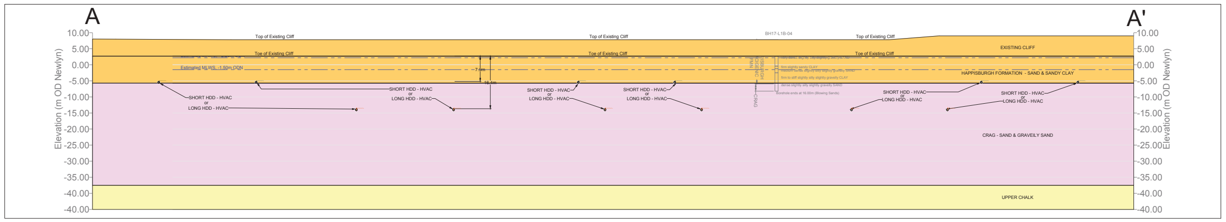

END VIEW A-A'

NOTES

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DO NOT SCALE

Rev	Date	Description	By
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Client: VATTENFALL WIND POWER LTD

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Designed by	Checked by	Approved by	Date approved
TR			

Drawing Number: 20171201RA-C/03

Issue: A

Project Title: VANGUARD & BOREAS HDD FEASIBILITY STUDY

Drawing Title: END VIEW OF CONCEPTUAL HDD DESIGNS - HVAC, HAPPISBURGH

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