Appendix B.1:
Horizontal Directional Drilling (HDD) Feasibility Report

Co-financed by the European Union
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NCT Revision	**Contractor Revision**	**Issue Date**	**Reason for Issue**	**Author**	**Reviewer**	**Approver**

HORIZONTAL DIRECTIONAL DRILLING (HDD) FEASIBILITY REPORT

Document Originator	**Project Name: NorthConnect**		**Total Pages**
RIGGALL & ASSOCIATES LTD.	**NCT Document Number**	**Contractor Document Number**	
Contractor Logo	**NCFFS-NCT-Z-RS-0001**	**20160401RA-C-FR01**	**73**
	TAG Number		
	Co-financed by the European Union Connecting Europe Facility		

Riggall & Associates Ltd.

HORIZONTAL DIRECTIONAL DRILLING (HDD) FEASIBILITY REPORT

NorthConnect Cable Landfalls Longhaven, Peterhead, U.K.

Client: Allen Gordon / NorthConnect

Date of Issue: 14th May 2018

Report Reference No.: 20160401RA-C-FR01

Report Issue: 02

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1. INTRODUCTION

1.1. Overview

Allen Gordon, acting as the UK Civil Lead for the proposed NorthConnect HVDC Interconnector between Peterhead and Norway, has sought expert opinion on the feasibility of Horizontal Directional Drilling (HDD) for proposed landfalls of offshore cables from the NorthConnect project.

The NorthConnect project is a 1400MW HVDC link between Norway and Scotland. It is planned to connect to the transmission system at a 400kV Converter Station near Boddam, Aberdeenshire. The landfall route has already been selected (Figure 1) and HDD has been proposed for the landfall of the offshore cables taking them from a nearshore position beneath the cliffs to join the trenched land installation.

The cliffs are covered by SSSI, SPA, and SAC environmental designations; HDD would minimise environmental impacts on these areas as well as offering construction advantages over a trenched installation.

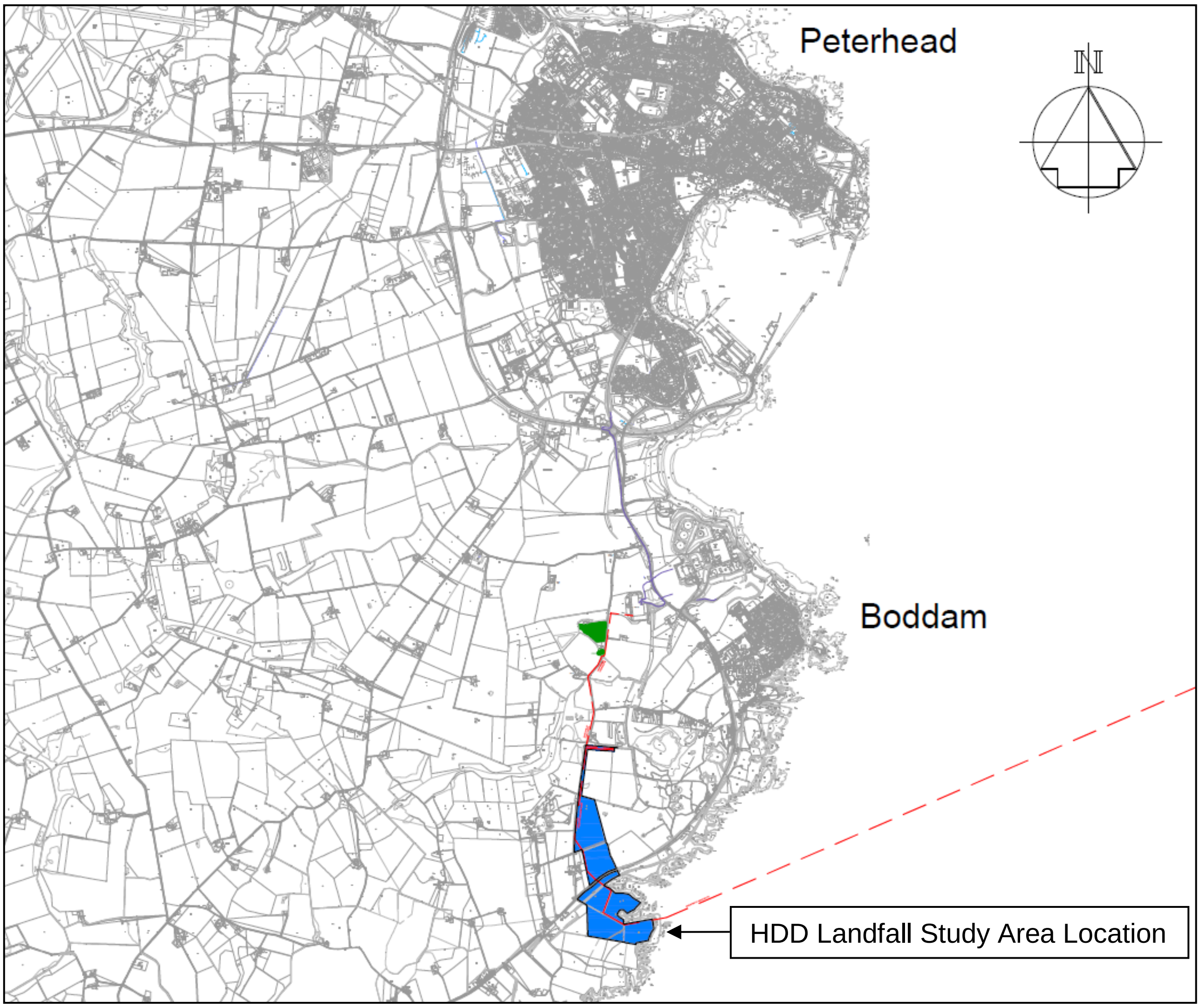

Figure 1. Overview of proposed route for NorthConnect cable. Figure taken NorthConnect KS Drawing No. 3136.

1.2. Scope of Work

Riggall and Associates have been invited by Allen Gordon to undertake a site visit and examine documents related to the project. The aim of this report is to apply our knowledge and expertise in HDD and geotechnical engineering / geology to give an independent assessment of the viability and design of HDD's to effect cable landfalls near Longhaven.

This purpose of this document is to:

- Review the available geological information and make recommendations for any further ground investigation work
- Provide a conceptual HDD design
- Provide an outline drilling methodology suitable to the conditions
- Assess the viability of the conceptual HDD design through hydrofracture modelling, drilling forces modelling, and calculation of duct installation forces
- determine likely equipment requirements by modelling drilling forces and duct installation forces for the HDD
- provide an indicative programme for the HDD works
- provide a high-level risk assessment of the HDD
- identify any additional risks, mitigations measures, or opportunities for the landfalls

The initial (Rev00) version of this report was completed prior to offshore and onshore investigations. This version (Rev02) takes into account LOTA Offshore Investigations undertaken in December 2016 and onshore ground investigations undertaken in late 2017 to early 2018.

1.3. Reference Documents

The documents supplied by Allen Gordon for review are outline in Table 1 below.

Table 1. Documents supplied by Allen Gordon for review.

Filename	**Title / *Description***	**Doc No. and Issue**	**Author**
2013.12.18_NorthConnect_TEC_HDD Technip Landfall Options Study Report.pdf	NorthConnect Landfall Option Study *High level appraisal of 3 potential landfall sites resulting in Location 1 as preferred site.*	Project No. : 1076 Document No. : TOWL 1076 RT ENG 001 Revision No. : Rev1 Date: 18/12/2013	Technip Offshore Wind Ltd
2016.01.06_NORTHCONNECT_PER_DRA_HVDC_CABLE_SEARCH_CORRIDOR_3136_A.pdf	HVDC Cable Search Corridor *Drawing indicating HDVC cable search corridor(land) and indicative DC cable route.*	Drawing No. : 3136 Rev No. : A	NorthConnect KS
Technical data NOVA-L 500 kV 1x1600 mm2 Cu.pdf	*Technical data for Nexans' NOVA-L 500 kV 1x1600 mm2 Cu cable.*	None given	Nexans
102273-NOC-MMT-SUR-REP-SURVEYLA.pdf	NorthConnect LOTA Geophysical and Geotechnical Route Survey – Survey Report	Document No. : 102273-NOC-MMT-SUR-REP-SURVEYLA Revision No. : Rev02 Date: January 2017	MMT Sweden AB

Filename	**Title / *Description***	**Doc No. and Issue**	**Author**
102273-NOC-MMT-SUR-DWG-ALNOC001.pdf	Geophysical, Benthic and Geotechnical Route Survey, NorthConnect, Alignment Chart, KP 0.000 – KP 4.690	Drawing Filename: 102273-NOC-MMT-SUR-DWG-ALNOC001 Revision: 02 Date: 2017-01-24	MMT Sweden AB
102273-NOC-MMT-SUR-DWG-NUHDD001.pdf	Geophysical, Benthic and Geotechnical Route Survey, NorthConnect, Alignment Chart, North Up Chart	Drawing Filename: 102273-NOC-MMT-SUR-DWG-NUHDD001 Revision: 02 Date: 2017-02-09	MMT Sweden AB
102272 Draft CPT_MMT.pdf	*Cone Penetration Test Records for CPT_A 001, 001_A, 001_B, 002, 003, 004, and 004_A*	CPT log status: Final	MMT Sweden AB
102272 Draft VC MMT.pdf	*Vibrocore records for vibrocores A_001, A_002, A_003, and A_004_A*	Core log status: Preliminary	MMT Sweden AB
170929 Intertek Metocean Report P2152A_R4323 Rev1.pdf	NorthConnect Metocean Data Study	Document No. : P2152A_R4323 Revision No. : Rev1 Date: 29/09/2017	Intertek Energy & Water Consulting Services
RSK Peterhead-R01(00) Geophysical Report (1).pdf	Geophysical Report, Peterhead, Scotland, NorthConnect KS Interconnector Convertor Station, Landing and Cable Routes	Project No.: 193047-Peterhead-R01(00) Rev: Final Date: 5th December 2017	RSK
BH201.pdf BH202.pdf BH301.pdf BH302.pdf	Draft logs and photographs for BH201,BH202, BH301, BH302	Draft	Structural Soils
18-022 - Cert 04 - Peterhead.pdf	UCS and Point Load testing results for BH201 and BH202	Date: 17/4/2018	MATtest Limited

1.4. Cabling and Ducting Options

The DC cable specification supplied at the time of writing this report is a Nexans NOVA-L 500 kV 1x1600 mm2 Cu, with an outer O.D. of approximately 125mm, approximated weight of 52kg/m, and a maximum permissible pulling tension of 315kN.

NorthConnect have requested that the size of the duct to be considered should be set at 560mm OD, until cable specifications have been finalised. The assumed duct size is therefore 560mm OD, 436mm ID, SDR9.

Thinner wall (e.g. SDR11) duct of the same diameter might also be suitable but would need to be assessed for installation and operational forces. Such forces could include negative internal pressure in the case that the installed, bentonite / water filled duct is sealed at the entry point but open at the seaward end.

NorthConnect have indicated that the requirements are for two cables and a fibre optic cable. For this report it is assumed that the cables will be installed in separate HDD's in order to maximise the thermal losses to surrounding ground. This report assumes that three separate HDD's will be required. The conceptual HDD designs indicate routes for three ducts but the final diameter of the HDD's has not been specified at this stage.

For HDD's the final bore diameter is generally between 1.25 to 1.5 times the duct / duct bundle diameter, with projects in stable ground tending to the lower values. Given the boreholes will be in granite the multiple is expected to be at the lower values. This study will assume the final HDD ream diameter will be 762mm (30") giving 1.36 times the duct OD. If ground conditions are favourable a 711mm (28") ream equating to 1.27 times the duct OD might be preferred for construction.

Table 2. Cable, Duct and Ream diameters assumed for this report

Item	Specification	Internal Diameter	Outer Diameter
Cable	Nexans NOVA-L 500 kV 1x1600 mm2 Cu	N/A	125mm
Cable Duct	560mm OD HDPE SDR9	436mm	560mm
Final HDD	Reamed to 30 inch	N/A	762mm

1.5. Elevation Datum

For this study the datum information at Peterhead provided on the Admiralty chart has been used for conversion of bathymetric data to Ordnance Datum (Newlyn). The datum used are given in Table 3 below:

Table 3. Elevation datum conversions used in the Feasibility Report and Drawings

Datum used for information in Report & Drawings		
DATUM	Admiralty (m above Chart Datum)	Ordnance Survey (m ODN)
MLWS	0.70 [1]	-1.50 [2]
MLWN	0.80 [1]	-1.40 [2]
MHWN	3.20 [1]	1.00 [2]
MHWS	4.00 [1]	1.80 [2]
Chart Datum	0.00	-2.20 [1]
Sources: 1. Admiralty Chart 2. Calculated from source 1.		

2. SITE VISITS

2.1. Initial Site Visit

An initial site visit was undertaken on 6/5/2016 by Tim Riggall to assess the site and investigate the local geology. Alan Neary from Allen Gordon met Tim on site. An approximate walking route of the site visit is shown in Figure 2 below. The weather was dry with light clouds and low wind.

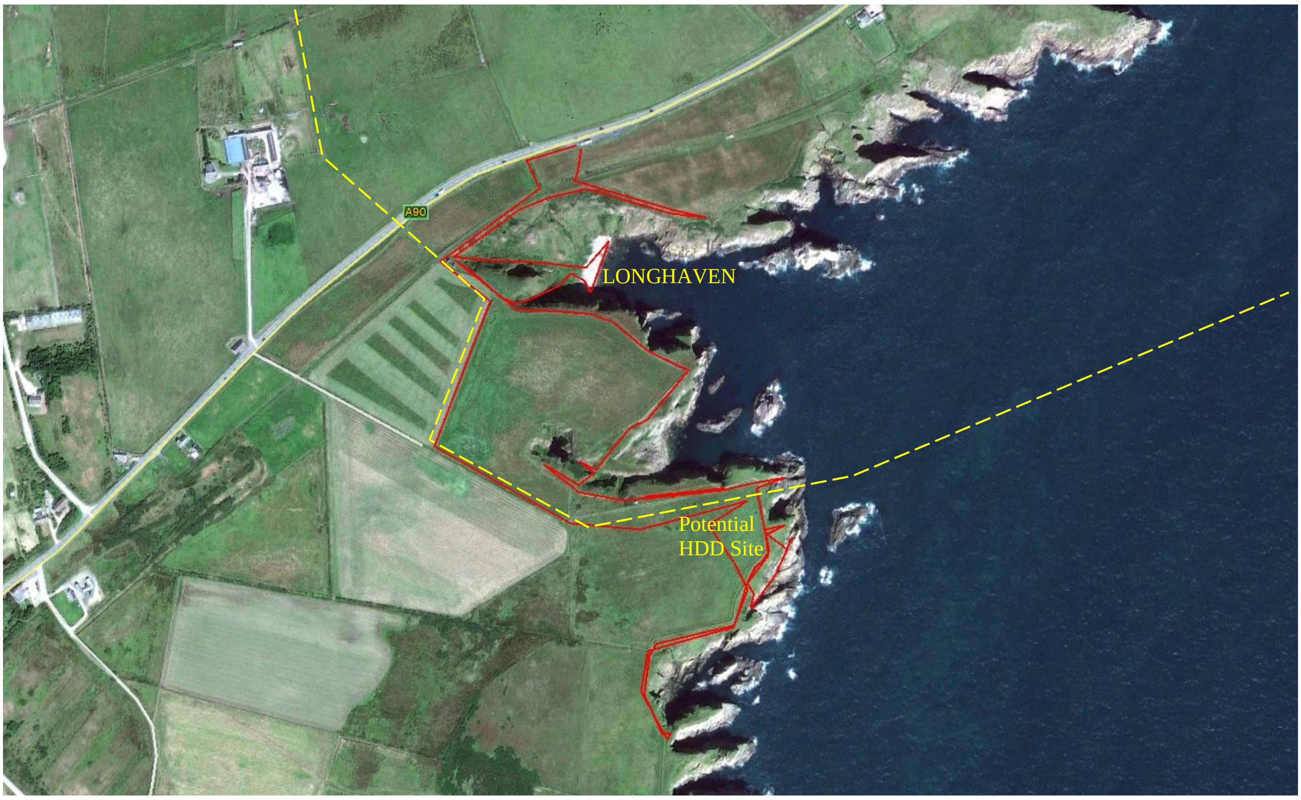

Figure 2. Approximate route walked during site visit shown in red, indicative cable route shown yellow dashed.

The primary aims of the site visit were to assess the impact of the site topography and geology on potential HDD routes and HDD site setup.

The topography of the area is dominated by granitic coastal cliffs up to 55m high. The cliffs east of the proposed HDD rig site are up to 25m in height and are some of the lowest and least steep along this stretch of coastline. The potential site for the HDD rig is flat with a gentle slope towards the eastern fence line of the field. On the western edge of this flat area the slope steepens with an elevation increase of approximately 5m.

The cliffs to the north and south of the headland containing the site are near vertical with one section of the northern cliffs appearing to be undercut (Figure 3). The rock structure of the undercut area looks to be controlled by an east-west shear zone with a steep northerly dip.

On the north-eastern corner of the headland Alan Neary pointed out a possible HDD alignment where a weathered shear zone formed a sloped route down towards the sea (shown in Figure 5 below). This alignment has been named the northern HDD Alignment on the Rev00 Feasibility Report Drawings (20160401RA-C/01 and 20160401RA-C/02, Rev0 report). There are no apparent slip planes in the granite and no mineral veining that would suggest a major fault, however the zone is much more weathered than surrounding rock (Figure 6) and the fabric of the rock is lightly foliated. The zone appears to align with the undercut area on the northern cliffs shown in Figure 3.

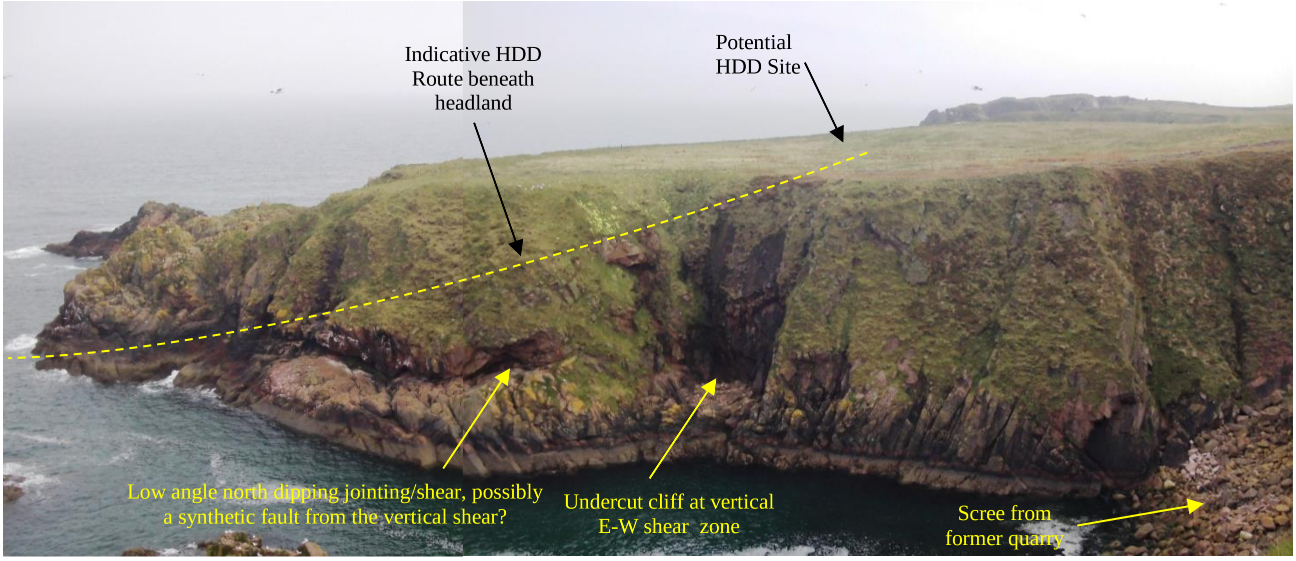

Figure 3. View towards the south showing potential HDD location and cliffs to the north of the site.

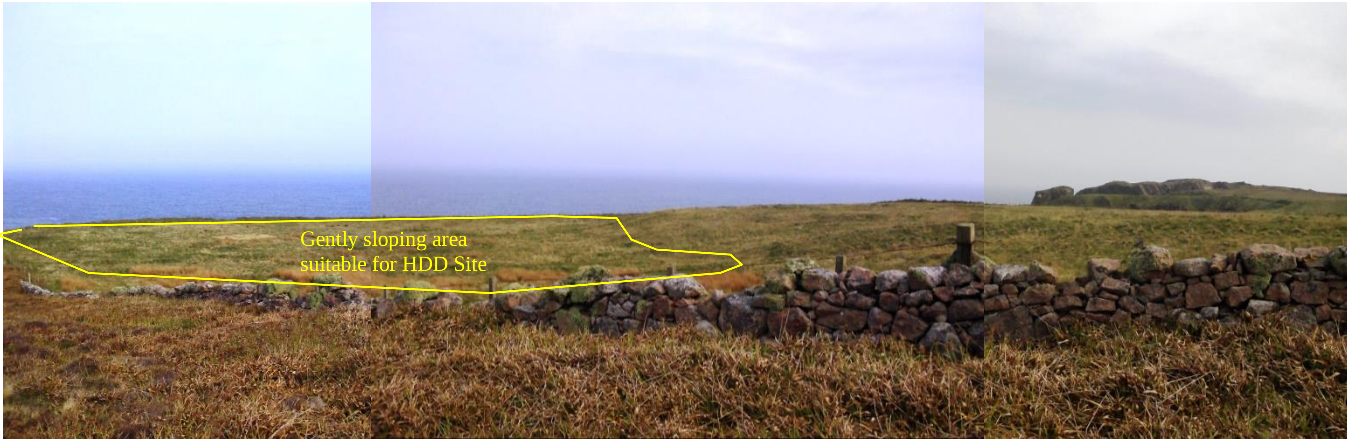

Figure 4. View towards the southeast showing the flatter area suitable for the HDD site with ground rising to the west (right of the photo).

To the south of this shear zone, and therefore south of the Northern HDD Alignment, are steep cliffs surrounding a rock pool connected to the sea (Figure 7). This appears to be formed from the intersection of a north-easterly aligned near vertical shear (estimated at 80°→315°) one to two meters in width and a smaller shear dipping at 70°→250°. The edge of the rock pool and cliff is potentially only 15m from the route of HDD2 on the Northern HDD Alignment.

Water pools along the shear zone; indicating that any fractures in the zone are likely to be very close spaced and clay filled or completely closed. There were no locations on the site visit where it was apparent that ground water was seeping from joints but there were many locations where water draining from the fields along the top of the granite was flowing or seeping down the cliff faces.

Running sub-parallel to, and east of, the shear zone forming the pool in Figure 7 is the shear zone shown in Figure 8. This zone is near vertical (average orientation 80°→300°) and passes across the route of the Southern HDD Alignment. The zone's orientation parallel to the coastline results in a less steep coastal profile. The overall profile for the Southern HDD Alignment slopes at approximately 25°, as opposed to 30° or more for the Northern HDD Alignment. This shear zone can be seen continuing through Watery Haven on to the south of the site and into the cliffs on the southern side of the Haven (Figure 9).

Figure 5. View towards the east along the Alignment of the Northern HDD route. The small gorge follows a steeply north dipping (east-west trending) shear zone. While no slip planes are apparent in the shear zone the granite is more weathered than the surrounding rock. This shear zone appears to be the eastern extension of the shear in the undercut area of cliff shown in Figure 3.

Figure 6. View towards the west at the shear zone shown in Figure 5 showing the weathered nature of the foliated granite. Because of its lower topography water draining from the fields flows through the zone, further increasing the weathering and erosion. For scale, the document holder is A4 size.

Figure 7. View northward towards the Northern HDD Alignment showing the steep cliffs down to a pool. The closest HDD in the Northern Alignment would be approximately 15m north of the undercut section and at a level of approximately the base of the pool.

Figure 8. The trace of a South-southwest trending, near vertical shear zone forming a small valley along the coastal slope. Viewed towards the south.

Figure 9. The continuation of the shear zone shown in Figure 8 as viewed from 170m to the south. View is looking northwards across Watery Haven.

Between the coastal low water mark and the small rock outcrop named as Hare Craig lies the Gutter of Nesh. This channel is likely to be formed along a north-south fault or shear zone. The depth of the seafloor is not known and there is potential for bedrock being deeper than the seafloor and infilled with sediments. Nearshore geophysics would be useful for identifying the bedrock position here if the water depth permits it.

Figure 10. Soil profile from an exposure near the abandoned quarry 150m northwest of site. The pen at bottom left indicates the scale.

The local soil profile is exposed at a number of places along the cliff edges and around the margins of the former quarry workings to the northwest of the HDD site. The soils are generally clayey sand with some angular gravels. They appear to be between 1m to 3m thick overlying the granite bedrock. It is probable that in places there will be cobbles and boulders of weathered granite corestones overlying the bedrock surface.

The morphology of the potential HDD site is gently sloping towards the east at approximately 1 in 15. The western edge of the potential site is formed by a steeper slope of approximately 1 in 3 with a 5m elevation increase before levelling out further west. The westernmost section of the potential site is slightly less well drained but overall the site will be well drained once the topsoil has been stripped for site preparation.

Access to the site is from the A90 through two fields. The fields are mostly well drained with boggier areas around gates. They are likely to provide good access once topsoil has been stripped and laid with geofabric and hardcore or gravel.

2.2. Second Site Visit

2.2.1 Landfall location

A second site visit was undertaken on 4/10/2017 to review the landfall location following the offshore survey and to review the location of planed ground investigations. Tim Riggall joined the following personnel on site: Gary McCann, Eckhard Bruckschen, Mikael Rosendahl, Henning Augestad, and Lucy Quinn.

The team indicated that the preferred HDD site is now on the higher ground to the NW of the area originally proposed in the Rev00 report. The revised site is indicated in red in Figure 11, the previously considered area is in yellow. The revised location is approximately 6m higher elevation and would result in increased cable pull-in tensions, however the cable specialists on the team have determined that these are within the acceptable range for the proposed cable.

Figure 11. View towards the southeast showing the revised location of the HDD site in red (right of the photo).

The revised HDD site is on ground gently sloping to the east. The area is grassed, probably grazing land, and is easily accessed through the field gate, although the area around the gate itself is boggy. There is a slightly raised (0.5-0.8m) stony lineament in the middle of the area estimated as being between OS Coordinates 412080 E, 839990 N and 412105 E, 839990 N. The line might represent an abandoned stone fence but there is nothing that correlates on any of the historical mapping.

The depth of soil and superficial deposits beneath the revised site is not known but bedrock is expected to be relatively shallow, possibly at 3m depth. Exposures in the face of the quarry located northwest of the site show that bedrock is at 1-3m below ground surface there with similar ground conditions in the adjacent field.

The revised location is very suitable as a HDD site. The location changes the alignment of potential HDD routes slightly and the different options available are explored in Section 4.

2.2.2 A90 and abandoned railway location

As a part of the second site visit on 4/10/2017, the potential location of HDD crossings beneath the A90 and the former railway were examined. Located approximately 500m inland from the landfall location the A90 and former railway could either be crossed as a single HDD or as separate HDD's or trenchless crossings.

The decision on whether to undertake the crossing as a single crossing or two separate crossings will depend on the results of ground investigations and contractor's preference. The option of two separate HDD's is only expected to be marginally less expensive than a single HDD, so the practical options are likely to be a single HDD or separate crossings using other trenchless methods such as auger bore or pipe ramming.

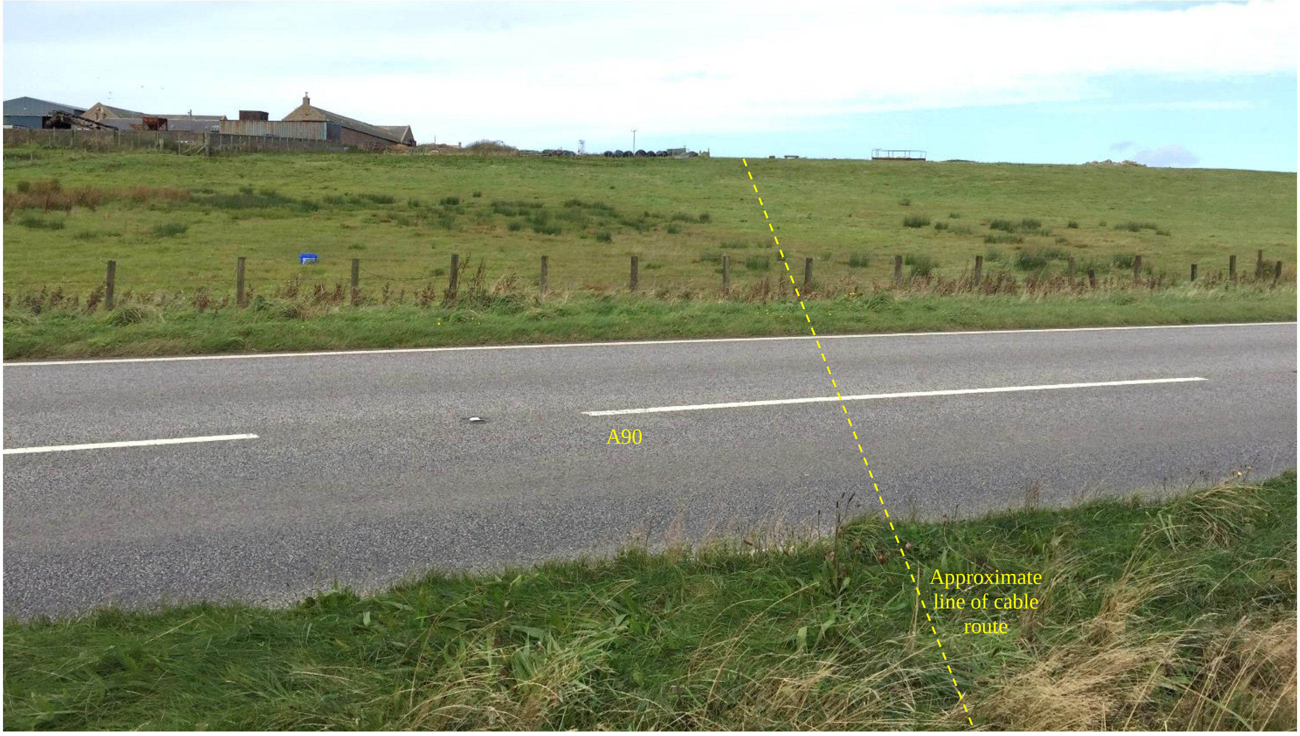

Figure 12. View to the northwest showing approximate cable route beneath the A90.

Figure 13. View to the west showing approximate cable route beneath the A90.

Figure 14. View to the north showing approximate cable route beneath the abandoned railway.

There was no direct evidence on the site walkover of the depth to bedrock. The railway is in a 1.5m to 1.8m depth cutting so assuming 1.5m cable burial depth and drive or reception pit would be 3m to 4m depth.

The A90 has a 0.5m embankment on its western side and a 2m embankment on its eastern side at the probable crossing location. The fields either side of the A90 slope moderately to the east but are not expected to require earthworks to host a HDD site.

3. GEOLOGY

3.1. Superficial Deposits - Land

The site contains only a thin layer of superficial deposits. From the site visit the thickness is expected to be 1-3m over solid bedrock and potentially up to 5m depth above weathered shear zones.

In the field there is expected to be a thin (0.3 - 0.5m) humic layer overlying silty SAND with gravel. With depth the gravel component is likely to increase in size and percentage. Towards the base of the superficial deposits there are likely to be cobbles and boulders formed from weathered granite corestone. An indicative soil profile is shown in Figure 10.

Results from BH201 indicate that the HDD locations will probably encounter soft sandy slightly gravelly CLAY, with occasional boulders, in the top 2m of ground. Underlying this will be 4m of cobbles and boulders of granite with some sand. The geophysical information from Resistivity Line 1 matches the results from BH201.

3.2. Superficial Deposits - Marine

The MMT 2016 LOTA marine geophysical and geotechnical survey identified a sequence of thin loose surficial Holocene sediments (silt sand and gravel) overlying dense sand and Glacial Till in the areas near potential HDD landfalls. At the probable HDD exit points the Holocene sediments are identified as silt and fine sand, while in the centre of the survey area near the shoreline it is identified as sand to gravel with ripples.

The summary table of interpreted geology from the offshore report is reproduced in Table 4 below. An excerpt from the Geophysical, Benthic and Geotechnical Route Survey drawing is provided in Figure 15 that indicates the expected superficial geology in the area of the HDD exit point. The results from the marine geophysical survey have also been overlaid on Drawing No. 20160401RA-C/10 in Appendix E of this report.

Table 4. Shallow geology units and expected lithology summary. Taken from Offshore survey report 102273-NOC-MMT-SUR-REP-SURVEYLA .

INTERPRETED STRATIGRAPHY	LITHOLOGY	BGS CORRELATION
Surficial Holocene sediments	Silt, Sand and Gravel in different proportions, locally containing shells pebbles or cobbles and boulders. Occasional clay lenses may occur. Locally mobile sediments occur. Primarily loose sands (lithology verified with geotechnical sampling).	Recent and/or Forth Formation
Late Weichselian to Holocene	Dense SAND and SILT.	Forth Formation (Upper)
Late Weichselian	Very soft to stiff sandy CLAY, partings and layers of sand.	Forth Formation (Lower)
Weichselian deposit	Glacial deposit /till. Unsorted sediment, soft to stiff clay with interbeds of sand and pebbly sand, and layers/lenses of coarse sand and gravel.	Wee Bankie Formation
Silurian	Bedrock	Peterhead Pluton granite

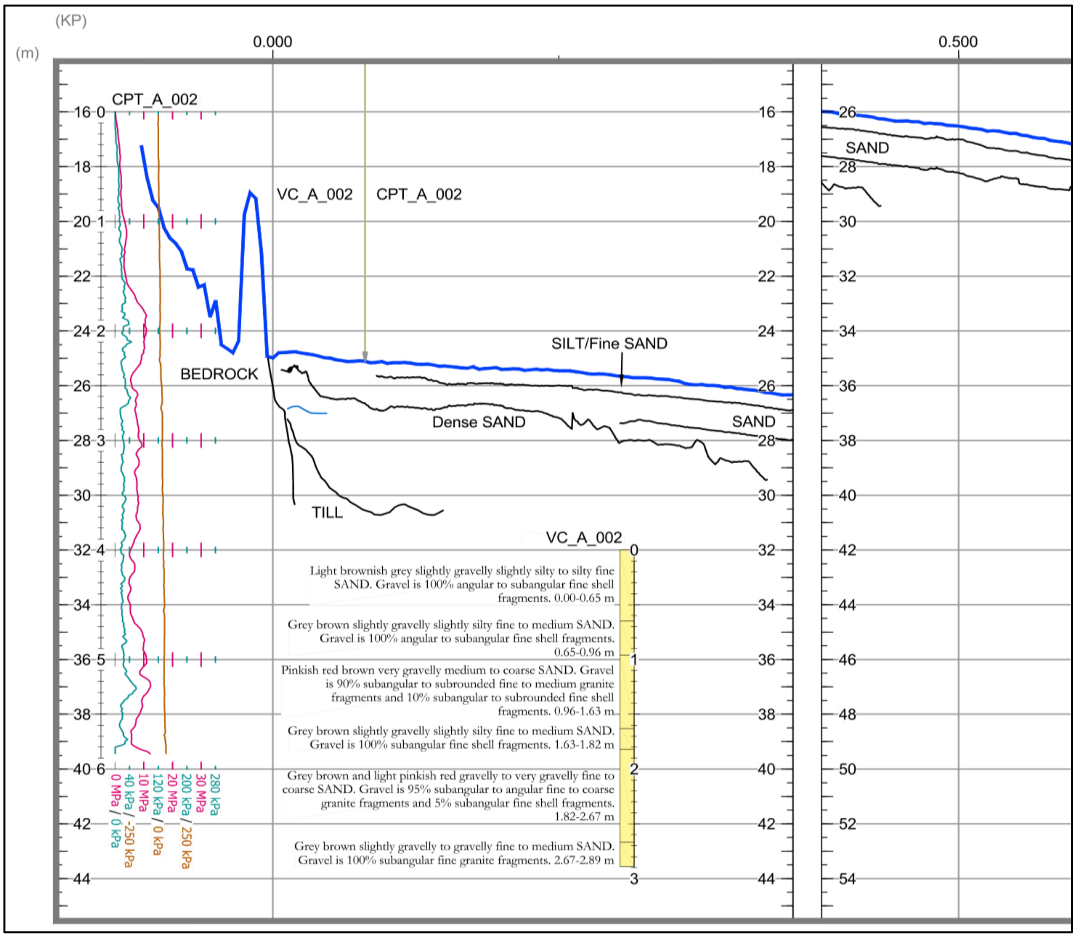

Figure 15. Excerpt from Drawing 102273-NOC-MMT-SUR-DWG-ALNOC001 of the 2016 Geophysical and Geotechnical offshore survey. Profile shown is from the Starboard line.

3.3. Granite Bedrock

BGS mapping indicates that the HDD site is underlain by Granite of the Peterhead Pluton and is of Silurian (416 – 444 Ma) age. The site visit found all of the exposed rock to be pink, coarse grained, Peterhead granite. No evidence was found of carboniferous intrusive rocks that are present in east-west orientations further north and south on the coastline.

The granite outcrops as massive with jointing usually spaced at 0.5 to 3m with closer spaced jointing (0.1m to 0.5m) locally near fault/shear zones. Fault/shear zones appear to be near vertical with the primary orientations being:

- trending north-south
- trending to north-north-east
- trending east-west

Locally there appear to be low angle synthetic faults branching from the main faults (Figure 3).

The fault/shear zones observed on the site visit were lacking in conspicuous fault planes or slickenside surfaces, but the granite was usually foliated and always significantly more weathered than surrounding rock (Figure 6). The observed zones were typically 0.5m to 3m in width.

The Unconfined Compressive Strength (UCS) of the fresh granite is potentially 200Mpa or higher. Granite in the weathered fault zones might be as low as 40MPa depending on the degree of weathering. Edmond and Graham (1977) note that weathering in the Peterhead granite reaches a depth of 56 m in a fault zone identified in the Peterhead Power Station water intake tunnel construction. However, the majority of either HDD Alignment is expected to be within fresh rock and even the weathered rock is of a strength that would be considered medium to hard rock for HDD drilling.

At the time of this report, initial UCS and Point Load testing from boreholes BH201 and BH202 has been received. One UCS test was taken from BH201 (33.9MPa) and two from BH202 (73.1MPa and 67.9MPa). These results are lower than expected. Looking at the core photographs the chosen sections may have contained pre-existing axial / sub-axial fractures in the samples selected. Further UCS tests from the core have been planned but no results received as yet.

In contrast, the Point Load tests from BH201 and BH202 give values that are closer to what might be expected from the granite. The Is(50) readings are typically in the range of 4 to 8 MPa, and using a factor of 24 they indicate UCS strengths of 96MPa to 192MPa.

Drawing number 20160401RA-C/07 (Appendix E) show a sectional view with the interpreted geology based on the site visit, ground investigations (boreholes and geophysics), and interpretation of structural lineaments from aerial photography.

Note that the continuation of the granite offshore is an assumption; there is no direct evidence of the bedrock material beyond Hare Craig. However locally there are granite outcrops offshore (e.g. Skerry Rock, 500m offshore from Boddam) and the BGS offshore index mapping shows the granite bedrock extending to 1.75km from shore. Granite continuing to the possible HDD exit location 250m from the shoreline is therefore considered to be very probable.

3.4. Hydrogeology

The BGS Hydrogeology 1:625,000 scale mapping designates the Peterhead Pluton as a low productivity aquifer with “small amounts of groundwater in near surface weathered zone and secondary fractures; rare springs”. This description matches the site visit observations that groundwater flowed from the base of the superficial deposits at the cliff lines. There were no observed flows from joints or shear zones in the granite.

Boreholes BH201 and BH202 encountered no groundwater. Borehole BH201 was drilled with air mist and water flush and did not have water returns during the drilling. BH202 was drilled predominantly with water flush with returns generally 70-80%.

3.5. Suitability of Geology and Groundwater for HDD

The land superficial deposits, because of their limited thickness, will only be encountered in the initial 20m of HDD drilling. Outcrops of the silty sand and gravel generally form near vertical faces in cliff top exposures and should form a stable borehole, but their limited depth means they are only likely to be exposed in the entry pit.

The underlying boulders and cobbles of weathered granite might need to be cased to ensure stability and drilling fluid returns to the entry pit. A 20m casing length is a relatively short length for HDD. And could be installed by a downhole casing hammer or by washing in casing after an initial pilot and ream through the deposits.

The granite is expected to form a stable borehole. There is a potential risk of localised collapse of small blocks from the roof of the HDD in areas where it passes through closed spaced joint sets. The site visit suggests such conditions only exist proximal to shear zones. Given the final ream diameter of 762mm the size of blocks that might collapse can be expected to be relatively small (100mm to 300mm size). Additionally, the site investigation found no real infill on jointing and they were generally closed (i.e. there was no visible gap between the sides of the joints), further reducing the chance of a block collapsing from the roof. Nevertheless, the HDD drilling and reaming equipment should be designed to allow any collapsed cobbles to be cleaned out of the borehole.

The fault zones and shear zones are only likely to be noticed as zones of faster drilling during the HDD. There is no evidence that they will contain significant volumes or flows of groundwater.

The high strength of the granite will result in slow drilling rates and greater than normal wear on the drilling equipment. These are factors that HDD contractors will need to price into their costs and programme.

The entry elevation and jointing in the granite suggests that loss of drilling fluid is possible when the vertical depth of cover is less than 10m based on projects in similar conditions. There is potential for drilling fluid to migrate a greater distance horizontally and this needs to be taken into account for designs running parallel to cliffs and steep slopes. A length of casing through these deposits would assist in mitigating fluid loss risks in the zone.

A cable landfall for the Hywind project was successfully drilled through Peterhead granite for the Hywind project in August 2016. The HDD drilling contractor was LMR drilling and by their account the drilling and installation was relatively straightforward. Further details are given in Section 11.2.

The marine superficial deposits are expected to be suited to the HDD technique. Upon exiting the granite the HDD is expected to encounter stiff Glacial Till followed by dense sand and finally a thin veneer of loose silt and sand. Much of the thin silt and sand around the HDD exit might be eroded due to the flow of drilling fluid from the borehole during the final reaming stages.

Where ducts are to be pulled into the HDD from sea, there is the potential for gravels and cobbles to be dragged into the borehole and potentially result in the duct becoming stuck. There is no indication of such problematic sediments from the 2017 marine geophysical and geotechnical survey and this risk is viewed as very low. Gravels are identified in some of the Holocene sediments to the north of the proposed HDD exit, however they are contained within a finer sand matrix. Indications from the vibrocore photographs are that they pose a very low risk to duct installation from the sea.

An alternative method of pushed duct installation would eliminate the risk from sediments being dragged into the borehole during duct installation.

4. CONCEPTUAL HDD DESIGN

For the Revision 0 of the feasibility study two HDD Alignments were assessed, a Northern route drilled towards bearing 070° (OS Grid) and a Southern Alignment drilled towards 120° (OS Grid). For each Alignment two vertical designs were drawn, a shallow design and a deeper design.

Following the results of the Marine Geophysical and Geotechnical survey, an exit near the Southern alignment was preferred. For Revision 1 of the report, a number of different options for exiting in the southern area were considered, the designs being named Southern Designs 3, 4 and 5.

This Revision 2 of the report has been undertaken based on additional information from draft onshore borehole and final onshore geophysical survey information. Southern Design 5 is the current preferred alignment because it balances depth of cover beneath the intertidal / gutter of nesh area, lateral distance from the cliffs south of the site, alignment for onward cabling toward the substation, and more favourable conditions at the exit point.

In plan view the three HDD’s for Southern Design 5 are 10m apart for the length of the drill. It is possible to reduce the proximity to 5m at entry if required and increase the separation at exit if needed for offshore works.

Final designs might require a different geometry to account for any new information from ground investigations, offshore requirements, or depth and cable separation requirements for thermal conductivity.

4.1. Design Profile

The conceptual design profile is shown in Appendix E on drawing number 20160401RA-C/07 (Southern Design 5). The main parameters of the designs are given in Table 5 below.

Table 5. Main Parameters of the Conceptual Southern Design 5 HDD

Alignment Bearing (OS Grid)	108°
Entry Elevation	+38.38m ODN
Entry Angle	-17°
Entry Tangent Length	220.07m
Vertical Curve Radius	400m
Vertical Curve Length	153.59m
Exit Tangent Length	63.71m
Exit Angle	+5°
Exit Elevation	-28.10m ODN
Total Horizontal Length	398.70m
Total Drilling Length	409.10m

Drawing number 20160401RA-C/10 (Appendix E) shows Southern Design 5 in plan view with the key mapping results from the onshore boreholes, onshore geophysics and offshore surveys. It exits in an area where the seafloor is described as SILT and fine SAND.

The entry point in the field is designed at 17 degrees; this angle is towards the steeper limits for standard HDD rigs. It is intended to ensure depth is reached as quickly as possible, reducing the overall length of the HDD and maintain an angle close to that of the coastline. The exit point is chosen to keep the HDD length to a minimum as well as exit at a suitable angle for duct installation and onward cabling.

The vertical curve radius of 400m is within the limits of both the drilling equipment and the expected ducts. There is potential to increase the radius to perhaps 600m; this would decrease the drilling forces slightly when forward reaming to enlarge the HDD in the granite but will decrease the level of cover and potentially increase the risk of breakout.

4.2. Site Layout and Requirements

The HDD entry site is likely to be approximately 50m x 65m in dimension as shown in Figure 16 below and Drawing No. 20160401RA-C/03 (Appendix E). The layout is indicative and contractors will have their own preferred layout but there is sufficient room in the field to accommodate the required equipment.

Figure 16. Detail of HDD site showing indicative positioning of equipment for Southern Design 5.

4.3. Ducts

As outlined in Section 1.4 the ducting is assumed to be 560mm OD HDPE SDR9, PE100. The minimum recommended bending radius for SDR9 PE100 duct is 25 times the OD, so 14m. Assuming a design factor of 3.0 this becomes a minimum design radius of 42m. The 400m design radius of the HDD is well above the limits of the duct.

4.4. Minimum Radius and Tolerances

The 400m design radius is well above the limits of both the drilling equipment and the ducts. No positional tolerances have been set at this stage of design.

4.5. Existing Infrastructure and Utilities

It is assumed that there are no buried utilities in the vicinity of the entry location because of its position in open fields distant from any infrastructure; however a services search will be required prior to construction.

5. DRILLING METHODOLOGY

The conceptual design of the HDD is a relatively straightforward landfall drilling with the ground expected to be predominantly unweathered granite with zones of weathered granite where fault or shear zones are intersected. 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.

5.1. 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. It is anticipated that a supply will be provided tapped in to the mains supply running beside the A90.

A traffic management plan and haulage route for heavy equipment should be implemented prior to arrival of equipment. The site is accessed directly off the A90 and there are no overhead lines between the A90 and site.

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 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. The final specification of the anchor block should be designed to accommodate the expected drilling and installation forces imparted by the HDD rig.

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 barrier mesh should be placed around any open holes 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.

An indicative site layout for the HDD works is shown in Section 4.2.

The nearest residence, Station House, is 500m to the west of the site beside the A90 road. The HDD equipment will probably be visible from the residence but noise disturbance at the residence is unlikely to be a problem. The HDD site equipment is only likely to be audible at night during periods with easterly breezes.

Figure 17. Example HDD rig of the size likely to be used for the HDD's.

Other residences with a line of sight to the HDD location are Glen Ugie, 750m NNE on the A90, Longhaven Mains, 650m NW, and Station Farm, 620m West of site. Over these distances noise should not be a disturbance, particularly when ambient noise levels from the A90 adjacent to the residences is taken into account. The residences could have a clear view of the lighting towers on the site; however the lights would not be directed at the residences. Lighting arrangements might also need to be discussed with Peterhead Port Authority to ensure they do not affect shipping navigation.

5.2. Casing

The exposures of silty sand with gravel in the coastal cliffs indicate that surface casing is not necessarily required (see Section 3.1) but contractors might install it to reduce the risk of hole collapse and fluid losses in the superficial deposits. If casing is required it is only likely to be 20m in length and will either be washed over the pilot drill or installed with 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.

5.3. 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 will use a tri-cone drilling bit powered by a downhole motor (DHM) (Figure 18) to drill the pilot hole in the granite.

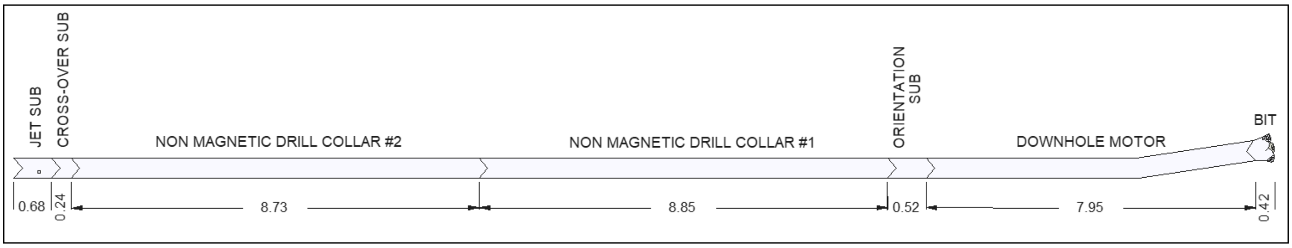

Figure 18. Schematic of Pilot Hole drilling assembly with downhole motor powering a tri-cone bit.

Behind the DHM will be the guidance probe followed by the drilling rods. Between the components there may be various connection subs to provide connections between differing types and sizes of threads. All connections are torqued to recommended values when they are added at the drilling rig.

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.

The downhole motor is powered by the hydraulic pressure of the drilling fluid allowing the bit to turn without need to rotate the drilling rods. To deviate along a curve the string of drilling rods is held at a fixed position (not rotated) and a bent sub behind the drilling bit allows the hole to be deviated with the bit being rotated by the downhole motor alone. To drill a straight section of hole the entire string of drilling rods is rotated.

Located behind the downhole motor, the guidance sensors 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 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 and calibrate the magnetic bearing of the HDD. On this project it is likely that the tracking cable will be extended as near as possible to the top of the cliffs 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.

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. A wireline cable inside the drilling rods is extended and connected before the new drilling rod is torque ready for drilling down.

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 30 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.

Unacceptable deviation of the pilot hole is unlikely because the granite is massive with even the weathered zones being of good rock strength and unlikely to deflect the drilling bit. However 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.

5.4. 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, however they are unlikely to be required for this project.

Bentonite drilling fluid is non-toxic however if sufficient quantity enters a 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 faster dispersal. However as a matter of course breakouts (loss of drilling fluid to the surface) are to be avoided and quickly remediated if they occur.

Bentonite is supplied in powdered form in either 25kg bags or 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.

The bentonite drilling fluid is circulated down through the drill rods and back up the outside the rods in the annulus of the borehole. Exiting into the entry pit, the fluid is then pumped to the mud recycling unit (Figure 19) 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 that any losses are recognised quickly.

Figure 19. A drilling fluid recycling unit with hydrocyclones and shaker screens on the upper level and active mud tank underneath. The blue bins capturing cuttings as they are removed by the shaker screens. On the right is a grey transfer pump for transferring cuttings from the entry pit (foreground) to the hydrocyclones and shaker screens.

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 because of 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. Because this HDD is in solid rock a PWD could be useful in giving early warning of insufficient hole cleaning, however this can also be diagnosed by monitoring of drilling cuttings returns and drilling forces.

5.5. Reaming

Once the pilot hole is completed the bit, downhole motor, and steering equipment is removed. For landfall projects the pilot hole is usually stopped short of the exit point 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 the project would be a 12.25” (311mm) pilot hole with reaming stages of 18” (457mm), 24” (610mm), and 762mm (30”).

To ensure the forward reaming follows the pilot hole, a short (1-3m) drill rod and a rounded “bull nose” is usually placed in front of the 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 hole opener.

For this project a rock hole opener with Tungsten Carbide Inserts (TCI) for cutting will be used (Figure 20) for the reaming. The HDD contractor will need to ensure that the reaming equipment is withdrawn periodically to check wear, thus avoiding loss of equipment in the hole.

Figure 20. Typical forward reaming assembly for rock containing a TCI rock hole opener (right) with rear centraliser (left).

Once all stages of the forward reaming 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 hole opener 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 hole opener where they remove the cuttings and flow into the sea.

5.6. Duct Installation

For HDD landfalls the traditional duct installation method is to pull the HDPE into the hole from exit towards entry. Because the HDD will be through solid granite and the final borehole is expected to be stable there is also the potential to install the duct by pushing it in from the entry point.

5.6.1 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 piece (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 21.

Prior to installation a cleaning run is preformed with a reamer of slightly smaller diameter than the final hole size, in the case of a 22” reamed hole a 20” reamer would normally be pulled through.

The duct will be prepared for installation by attaching a pulling head (Figure 22) and the duct is usually ballasted by filling with water to reduce its buoyancy. Because of the considerable length of borehole above sea level on this project, rather than a sealed duct, ports to allow air or water to enter at the pulling head might be considered. This would allow entry of air once the duct has been pulled above sea level in the borehole, significantly reducing the pulling force.

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 21. Typical setup of PE butt fusion welder

Figure 22. 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 30m 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. Because of the elevation difference between entry and exit the end of the pipeline might need to be secured to ensure the pipeline does not slip down slope in the hole.

5.6.2 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. The potential advantages of a pushed installation at this location are the reduction in offshore works with the attendant risk of weather delays, and a reduction in duct installation tensions.

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.

Figure 23. A pipe pusher (black unit at HDD entry point) installing 560mm HDPE on a 584m length HDD in Ireland (AMS Drilling).

If the duct has a closed end it 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. Alternatively the duct could be pushed open ended and fluid would fill the duct through the open end when it reaches sea level. The duct will then require pigging afterwards to remove drilling fluid from it.

If an additional PE line is required for grouting of the borehole after installation (see Section 5.6.3 below) the risks with a pushed installation increase significantly and additional pull from offshore might be required. The additional, smaller, duct is at risk of buckling during installation causing the main duct to become stuck. The risk can be reduced by fixing the smaller duct to a pushing cap on the seaward end of the main duct and strapping the smaller duct to the main duct. The only instance the author knows of using multiple ducts or pipelines for a pushed installation is the Billia Croo HDD in Orkney drilled by Stockton Drilling, however the smaller pipeline appears to have been steel.

The use of a cable and pulling head towed by a vessel to ensure the ducts are in tension would reduce risks during a multi-duct push. However, offshore assistance reduces one of the benefits of the pushed installation method, the reduction in marine works and weather dependency.

5.6.3 Post Installation Works

Following duct installation, a messenger cable is pigged through the duct using compressed air or water to propel the pig and the ends of the duct are sealed awaiting HV cable installation.

Based on discussions during the second site visit there might be a need to grout some or all of the annulus between the duct and the HDD bore to enhance thermal dissipation from the cables. Because of the entry elevation this would need to be undertaken as a staged operation. A section of borehole below the level of the exit point would need to be grouted first and allowed to set to create a plug for grouting of the sections above the exit level.

For grouting of the first plug section the most suitable method is probably to use a “tremmie” line. A PE duct would be pulled into the HDD during installation of the main duct. The PE duct would be of approximately 75mm to 100mm diameter and either the downhole end of the duct would be located at the lowest point of the borehole, or the duct would be pulled completely through the borehole with perforations in the duct positioned in the lowest section of the borehole.

Following installation of the PE duct (tremmie line), grout is pumped through the line to the lowest point of the borehole where it displaces the bentonite fluid until the level of grout reaches the seafloor exit of the HDD. When this section of grout has set, the section of borehole between the HDD entry point and the set grout can be filled with either bentonite or grout by pumping into the entry point of the HDD. If grout is used it should have a retardant added to ensure it has adequate time to flow to the base of the column and displace any bentonite fluid upwards to the HDD entry point.

5.7. Marine Support Works

Because the exit point is located 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 the 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 was done at the Hywind Peterhead landfall (see Section 11.2). Because the exit point is expected to be at -25mODN or lower for this project divers are likely to be used. 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.

For a pulled duct installation, these marine operations will be required from the time that the pilot hole exits to the seafloor until duct installation is completed. For a pushed duct installation the marine operations are mainly required between pilot hole exit and completion of any pull reaming.

Figure 24. Large barge with four point anchoring and workboat. On the right hand side of the barge the duct can be seen being pulled into the HDD. The water depth is approximately 4m.

6. HYDROFRACTUR E MODELLING

To better understand the risk of bentonite breakout on this project hydraulic fracture modelling was undertaken for Rev00 of this report as outlined in the following sections. The modelling has not been updated for Rev02 of the report because the Southern design 5 is of similar length and depth of cover to the Southern alignment examined in Rev00.

Hydrofracture modelling is usually used in superficial deposits rather than rock. For this project the modelling tests the scenario of drilling fluid utilising an open joint of significant width (>20mm) for breakout with the joint being filled with soft clay, soft sandy clay, or firm clay. A highly weathered shear zone would give similar results if it were encountered.

The use of hydrofracture modelling might be considered useful for determining the planned stopping point of the pilot before forward reaming commences. This could be undertaken by the HDD contractor when the final HDD design has been determined.

6.1. Methodology

Hydraulic fracture modelling examines the pressure required for drilling fluid to force its way through the ground to the surface. The programme is based on equations that account for strength characteristics of the ground. The equations were developed at the Technical University of Delft, Netherlands, and were published in the USA by the Army Corps of Engineers.

The Delft equations are based on plastic cavity expansion theory and account for the pressure required for plastic deformation and propagation of fractures from a cylindrical hole through a soil mass. The modelling incorporates the soil shear modulus as well as undrained cohesion and angle of internal friction to account for the behaviour of both cohesive (clays etc) and non-cohesive (silts, sand, gravel etc) soils.

Field use of the programme in superficial deposits with back analysis of field data has shown a good correlation between modelled and actual pressures inducing formation damage or breakouts. The programme has only been used on projects with rock drilling on three occasions because of the low susceptibility of rock to hydrofracture by drilling pressures. The modelling results for this project will be very conservative because they assume the occurrence of some very specific conditions; continuity of a fracture / joint to the surface, continuity of significant width in the fracture / joint for the entire distance to surface, and the infill in the fracture / joint being of low strength.

The geotechnical parameters required for hydraulic fracture modelling are soil cohesion, internal angle of friction, saturated density, and the shear modulus. The parameter values were chosen as representative of the soft clay, soft sandy clay, and firm clay in the scenarios. The parameters are given in Table 6 below.

Table 6. Geotechnical Parameters used in the hydraulic fracture modelling.

GEOTECHNICAL PARAMETERS					
Lithology	Description	Internal Angle of Friction, ϕ (deg)	Undrained Cohesion, c_u (kPa)	Shear Modulus, G (N/mm^2)	Saturated Desity, ρ_b (t/m^3)
Fault / Shear zone Infill - Extremely Weathered	soft CLAY	18	30	2.0	1.80
Fault / Shear zone Infill - Highly Weathered	soft sandy CLAY	25	10	5.0	1.80
Fault / Shear zone Infill - Moderately Weathered	firm CLAY	20	55	7.5	1.85

HDD HYDRAULICS & HYDROFRACTURE LIMITS

Hydraulics programme calculates downhole pressures losses and velocities in each section based on Power Law rheology model from API RP 13D 2003
Hydrofracture programme calculates limits based on the Delft equations, US Army Corps of Engineers CPAR-GL-98-1

NorthConnect - Northern Alignment - Deeper Design

Surface Configuration
Mud pump line to rig 3" — Length of mud line (m) 20.00 — I.D. 3 inches
Surface Casing — Length of casing (m) 10.00 — I.D. 24 inches

Drilling Assembly
Drill pipe
6 5/8" 27.7 lb/ft — I.D. 5.901 — O.D. 6.625 inches
User defined OD and ID (inches)

BHA
Collars
6 3/4" NMDC — Length of collars (m) 18.00 — I.D. 2.813 — O.D. 6.750 inches
User defined OD and ID (inches) — include O/S & X/O

Motor/Jet
6 3/4 " mud motor — Length of motor (m) 8.00 (incl bit + ext) — O.D. 6.75 inches
Pressure drop 1250.0 Bar

Bit/Reamer
Enter Nozzle sizes (1/32 inch) — nozzle 1: 18, nozzle 2: 18, nozzle 3: 18, nozzle 4: 0
Enter Total Flow Area (square inches)

Weepersub/nozzle in string
Add weeper/nozzle to string
Enter Nozzle size (1/32 inch)
Enter Total Flow Area (square inches)
Differential Pressure on motor

Hole Data
Hole size (in) 9.625

Pressure units
Pressure Units Bar

Joint No.	M.D (m)	Away (m)	Elev Bore (m)	Flow Rate (l/min)	Mud Weight (kg/l)	Fann 600	Fann 300	Fann 100	Fann 3	Vertical Depth (m)	Annulus Pressure bar	Hydrostatic Pressure bar	Total Annu Press Drop bar	Pressure at Guage bar
Entry	0.00	0	32.25	1200	1.03	60	40	25	15	0.00	0.2	0.0	0.2	#VALUE!
1	5.00	4.7815	30.7881	1200	1.03	60	40	25	15	1.46	0.4	0.1	0.2	#VALUE!
2	10.00	9.563	29.3263	1200	1.03	60	40	25	15	2.92	0.5	0.3	0.2	#VALUE!
3	15.00	14.3446	27.8644	1200	1.03	60	40	25	15	4.39	0.7	0.4	0.2	#VALUE!
4	20.00	19.1261	26.4026	1200	1.03	60	40	25	15	5.85	0.8	0.6	0.2	10.8
5	25.00	23.9076	24.9407	1200	1.03	60	40	25	15	7.31	1.0	0.7	0.2	10.8
6	30.00	28.6891	23.4788	1200	1.03	60	40	25	15	8.77	1.1	0.9	0.2	10.8

Figure 25. Example of parameters used for drilling fluid downhole pressure modelling.

To examine if the drilling fluid is likely to exceed the modelled soil strengths, the parameters from the drilling assembly, drilling fluid, and flow rate are used to model the annular pressure at the bit along numerous points of the drilling profile. The surface topography and drill profile is used to calculate the depth of the HDD at each point.

The drilling fluid downhole pressure modelling is based on American Petroleum Institute recommended practice API RP 13D 2003. The programme uses the Power Law rheological model to calculate downhole pressures losses and velocities in each section of the drilling equipment, the downhole assembly, and the annulus between downhole assembly and wall of the borehole. The model accounts for turbulent and laminar flow regimes. An example of the parameters used in this modelling is shown in Figure 25.

A number of scenarios were modelled to test the sensitivity of break out risk to:

- the size of the drilling bit
- fault / shear / joint infill material

6.2. Results

The output graphs from the modelling are shown in Appendix A. The graph from The Northern Alignment Shallow Design is shown in Figure 26 below in order to explain the interpretation of the graph.

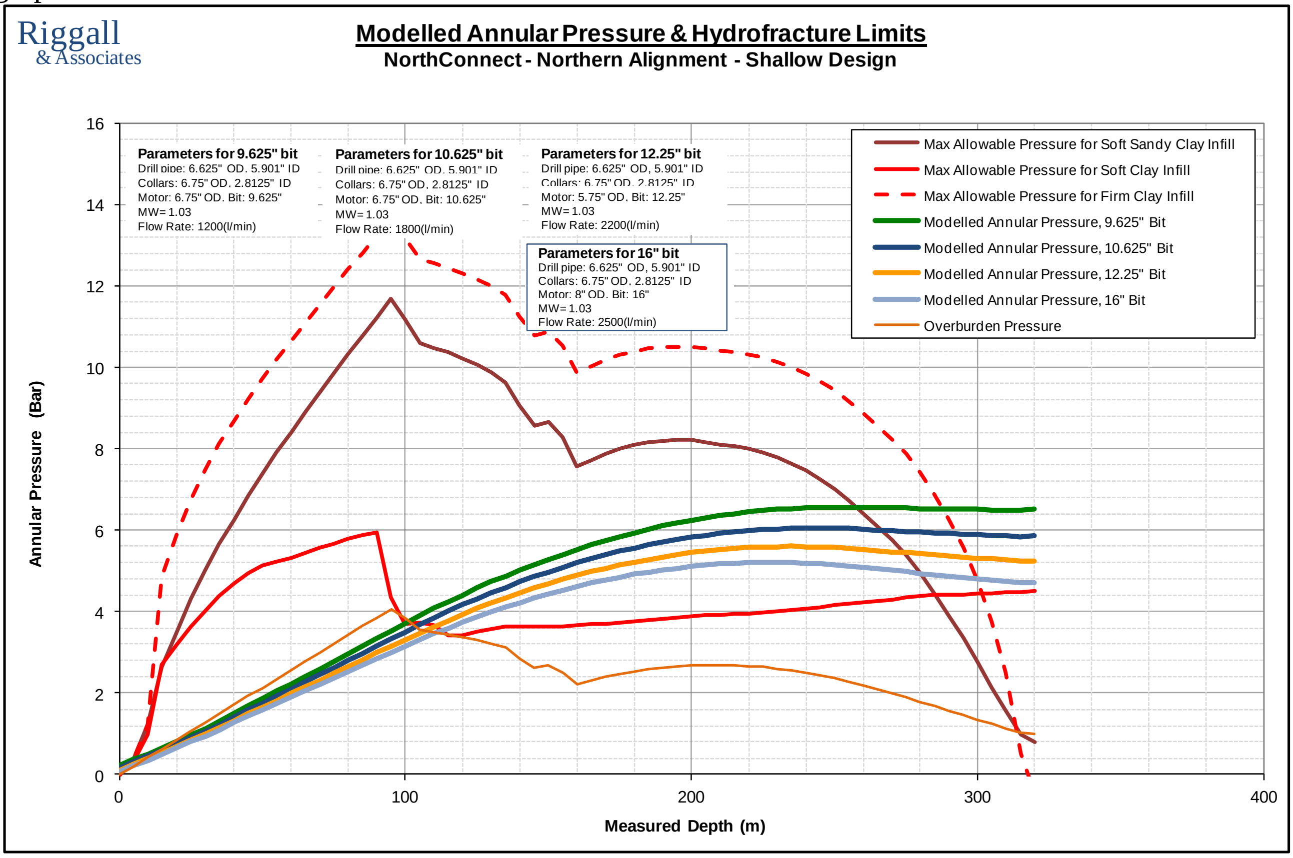

Figure 26. Output graph of Hydrofracture modelling Run 1

The thick red and burgundy lines in Figure 26 above show the theoretically derived annular pressure that would be required to cause hydrofracture to extend to the surface for each of the infill clay types. This would result in a breakout of drilling fluid at the surface if these pressures were reached and then maintained. The accuracy of these predicted maximum allowable pressures is dependent on the geotechnical parameters being representative of the actual clay infill in the fracture or joint. Additionally the width of the joint will affect the hydrofracture pressure, bentonite generally seals any fracture less than 10mm width and fractures less than 20mm width tend to gradually seal with a combination of fluid and rock cuttings.

The thick green, blue, and orange lines in Figure 26 represent the modelled annular pressure behind the drilling bit. In this case four different sizes of drilling assembly have been modelled. It can be seen on the graph that wherever the modelled annular pressure exceeds the maximum allowable pressure are points where the HDD could cause a breakout of drilling fluid at the surface. In the example above it can be seen that beyond 100m if the HDD encounters a fracture >20mm in width extending to surface and filled with soft clay there is a risk of causing a breakout. If the fractures are >20mm width and filled with soft sandy clay breakout might be expected from 260m Measured Depth (MD). If the infill material is firm clay breakout might occur from 290m MD. (Measured depth is the distance measured from the entry point to the drilling bit along the drilling route; essentially the complete length of drilling equipment in the hole).

The overburden pressure shown on the graph is the vertical pressure imparted by the column of soil and water overlying the HDD at any point. In simple terms it can be thought of as the mass of soil. It indicates the pressure at which the weight of the soil alone is sufficient to resist the annular pressure without requiring the additional strength in the soil provided by friction between grains, cohesion, or cementation.

The graphs in Appendix A for all four designs show very similar results. The only marked difference is that the Northern Alignment Shallow Design potentially breaks out 5-10m earlier for the firm clay scenario. This is because the design has an exit angle of 3° compared to 5° for the other designs so the depth of cover is lower as exit is approached.

The modelled annular pressures for the different bit diameters show a decrease in pressure with increasing diameter, however the risk of breakout has a low sensitivity to bit diameter. The largest bit diameter (16”) only defers the risk of breakout by approximately 20m over the smallest bit (9 $^{5}/_{8}$”) for the four different designs.

6.3. Conclusions

Based on observations from the site visit there is a low chance of the HDD encountering fractures of greater width than 10mm filled with soft clay or soft sandy clay. There is a potential for fractures filled with firm clay so potentially there is a risk of drilling fluid breakout to surface at a distance of 20 to 40m before exit. Breakout would require a vertical fracture (probably in a shear or fault zone) of 10mm width or greater. No jointing surfaces observed on the site visit had an infill width sufficient to give concerns of breakout risk.

A risk that is difficult to model and assess is that of drilling fluid escaping laterally to cliff faces while the HDD is drilled above sea level. The nearest cliff is 30m to the south of the southern HDD when it approaches sea level. The shear zone indicated in (Figure 9) is a potential pathway for drilling fluid, however the HDD will be 10m below sea level when it intersects the shear zone and breakout via this route is unlikely and should be able to be sealed if it occurs.

There is only a small benefit realised by using larger bit diameters in reducing the breakout risk. The pilot hole diameter should therefore be chosen to suit drilling considerations rather than for mitigation of bentonite breakout risk.

7. DRILLING FORCES CALCULATIONS

To determine the required specifications of drilling equipment the likely ranges of drilling forces were modelled for the longest of the Rev00 designs; the Deeper Design on the Northern Alignment (438m drilled length). The graphs from the modelling are contained in Appendix B.

The longest of the Rev01 Southern Designs, design 3, is of a similar length and would therefore have very similar forces to the modelled deeper design on the northern alignment.

The results of the modelling suggest the following maximum drilling forces:

- Maximum Push = 27 tonne force (assumes coefficient of friction = 0.6)
- Maximum Pull = 13 tonne force (assumes coefficient of friction = 0.6)
- Maximum Torque = 16 kN.m (assumes coefficient of friction = 0.6)

The actual coefficient of friction is expected to be 0.3 to 0.4 and can be significantly lowered by ensuring drill cuttings are removed from the borehole and sand content in the drilling fluid is low.

A check of the reaming passes indicated that if three reaming passes are used the maximum torque will be equal to the pilot hole torque for the final ream (24”-30”) with lower values for the preceding reams. However the torque can vary with a number of factors including the size of the reaming steps, the Weight On Bit (WOB) applied, and ground conditions (e.g. jointing and fracturing in the rock).

Based on the maximum forces the critical force for determination of the HDD rig size will be torque. During HDD drilling, and particularly during reaming, the torque can spike considerably above the theoretical value when variable ground conditions are encountered. When drilling into or out of fault/shear zones such torque spikes might occur on this HDD. It would be prudent to assume torque spikes could be double the modelled value. Therefore a rig with 34 kN.m capability or more should be considered. This equates to a rig with 70 tonne pull force or greater. Most HDD contractors prefer to operate with additional capacity and would probably view a 100t machine as a minimum.

8. PULLBACK CALCULATIONS

The expected forces for the duct pullback were calculated for the single 650mm OD, SDR9, PE100 ducts assuming the duct, installed on Design 5. The results are shown in Appendix C. The summary results are shown in Table 7 below.

Table 7. Summary of pullback forces for 650mm, SDR9, PE100 in a borehole with friction coefficient of 0.40.

SUMMARY OF PULLBACK CALCULATIONS FOR HDPE 560 mm OD PIPELINE		
NorthConnect -Design 5	**13th May 2018**	
Parameter	**560 mm, SDR9**	**Units**
Pipe weight, W_p	0.093	tonnes/m
Water Filled weight, W_{pw}	0.242	tonnes/m
Buoyant air filled weight, W_{ba}	-0.178	tonnes/m
Buoyant water filled weight, W_{bw}	-0.029	tonnes/m
Buoyant seawater filled weight, W_{bs}	-0.026	tonnes/m
Maximum Pullback Force - air filled	61.0	tonnes force
Maximum Pullback Force - water filled	31.4	tonnes force
Maximum Pullback Force - seawater filled	30.7	tonnes force
Maximum Pullback Force - open pipe	12.2	tonnes force

The 650mm duct has a maximum recommended pull of 133 tonnes (yield strength is 307) so there is adequate factor of safety in its design for pullback, particularly if the duct is water filled. The calculations assume a borehole friction co-efficient of 0.40 which is at the upper end of expected values.

The calculations using a water filled pipe and friction co-efficient of 0.40 indicate that the duct would not slide back down the borehole after installation. However if the co-efficient of friction is 0.30 or lower there is potential for the duct to slide downhole. The duct should therefore be tethered at the entry point after installation. In the longer term, grouting of a section at surface is likely to be required to stabilise the duct position; grouting would also exclude any surface runoff and groundwater from potentially flowing along the borehole.

The pullback forces are within the capabilities of the likely HDD rig.

The calculations only assess the installation forces on the ducts; a check of the long term stresses of on the ducts should be undertaken as a part of final design to ensure the ducts are fit for purpose. A potential risk is from vacuum forces if the seafloor end of the duct is opened / ruptured while the pipeline is water/fluid filled and the land end is still sealed. This could lead to collapse of the section of duct above sea level.

9. INDICATIVE PROGRAMME

An indicative programme of works for three HDD landfalls is shown in Table 8 below. The programme shows results for both 12 hour working per day and 24 hour working per day. For much of the HDD works there is the potential to work 24 hours provided there are no restrictions for environmental reasons.

Table 8. Indicative programme of works for Southern Design 5.

Indicative Programme - NorthConnect HDD's
Southern Design 5 - 13/5/2018

Length of HDD (m)	410	410
Length of Surface Casing (m)	20	20
Stopping distance before Exit (m)	60	60
Length of sediments at Exit (m)	40	40
Bull nose length (m)	5	5
Pilot ROP - Bedrock (m/12hr shift)	35	35
Forward Ream ROP - Bedrock (m/12hr shift)	30	30
Pilot ROP - Sediments (m/12hr shift)	120	120
Forward Ream ROP - Sediments (m/12hr shift)	80	80
Wireline tripping in ROP (m/12hr shift)	500	500
Rods tripping in ROP (m/12hr shift)	800	800

Activity		12hr Shifts	24hr Shifts
Access Road works		10.0	10.0
Site establishment works		10.0	10.0
HDD Duct #1	Mobilise, unload, position	5.0	5.0
	Rig & recycling setup	5.0	5.0
	Casing Installation 30": 0 - 20m	4.0	4.0
	Pilot hole drilling 12.25: 0 - 350m	10.0	5.0
	Forward ream 18": 0 - 345m	11.5	5.8
	Forward ream 24": 0 - 340m	11.3	5.7
	Forward ream 30": 0 - 335m	11.2	5.6
	Demobilisation to HDD #2	1.0	1.0
HDD Duct #2	Setup Rig	2.0	2.0
	Casing Installation 30": 0 - 20m	4.0	4.0
	Pilot hole drilling 12.25: 0 - 350m	10.0	5.0
	Forward ream 18": 0 - 345m	11.5	5.8
	Forward ream 24": 0 - 340m	11.3	5.7
	Forward ream 30": 0 - 335m	11.2	5.6
	Demobilisation to HDD #3	1.0	1.0
HDD Duct #3	Setup Rig	2.0	2.0
	Casing Installation 30": 0 - 20m	4.0	4.0
	Pilot hole drilling 12.25: 0 - 350m	10.0	5.0
	Forward ream 18": 0 - 345m	11.5	5.8
	Forward ream 24": 0 - 340m	11.3	5.7
	Forward ream 30": 0 - 335m	11.2	5.6
	Pilot hole drilling: 350 - 410m	1.6	1.6
	Barge/diver exit confirmation	1.0	1.0
	Back ream 18": 345 - 410m	1.8	0.9
	Back ream 22": 340 - 410m	1.9	1.0
	Cleaning pass	1.0	1.0
	Demobilisation to HDD #2	1.0	1.0
	Setup Pipe Pusher	1.0	1.0
	Installation of duct	1.0	1.0

Activity (continued)		12hr Shifts	24hr Shifts
HDD Duct #2	Setup Rig	2.0	2.0
	Pilot hole drilling: 350 - 410m	1.6	1.6
	Barge/diver exit confirmation	1.0	1.0
	Back ream 18": 345 - 410m	1.8	0.9
	Back ream 24": 340 - 410m	1.9	1.0
	Back ream 30": 335 - 410m	2.1	1.0
	Cleaning pass	1.0	1.0
	Demobilisation to HDD #3	1.0	1.0
	Setup Pipe Pusher	1.0	1.0
	Installation of duct	1.0	1.0
HDD Duct #1	Setup Rig	2.0	2.0
	Pilot hole drilling: 350 - 410m	1.6	1.6
	Barge/diver exit confirmation	1.0	1.0
	Back ream 18": 345 - 410m	1.8	0.9
	Back ream 24": 340 - 410m	1.9	1.0
	Back ream 30": 335 - 410m	2.1	1.0
	Cleaning pass	1.0	1.0
	Remove HDD Rig	1.0	1.0
	Setup Pipe Pusher	1.0	1.0
	Installation of duct	1.0	1.0
Rig Down & Demobilise HDD Equipment		5.0	5.0
Grouting HDD Annulus		9.0	9.0
Site reinstatement works		10.0	10.0
Weather Delay Days		4.0	4.0
Adverse Ground Delays		21.0	21.0
	TOTAL	268.1	194.5

Notes: ROP's include allowance for slow drilling
Adverse ground delays assume stop and grout of areas with large fluid loss
Casing installation for HDD's 2 and 3 could be potentially be run concurrently
Duct welding and stringing assumed to run concurrently

10. HIGH LEVEL HDD RISK REGISTER

A High Level Risk Register has been compiled for the HDD landfall(s). It intends to address environmental, safety, and project risk.

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	Personnel and equipment falling over cliffs	2	3	6	Fencing and barricades around site	1	3	3
					Site boundary clearly marked	1	3	3
					Site designed to be away from cliffs	1	3	3
					Coastal public footpath diverted through the fields during works	1	3	3
2	Release of drilling fluid to sea when drilling out exit affects sea life	3	2	6	Drilling fluid pump rate reduced as ground becomes soft	3	2	6
					Evaluate use of alternative drilling fluid or water	1	2	2
3	Toppling of vehicles on uneven / sloping ground	2	3	6	Access roads designed to avoid traversing slopes	1	3	3
					Speed limits appropriate to conditions	1	2	2
					All plant and vehicle operators to be suitably qualified	1	3	3
					HDD working site to be level or benched on steep ground	1	3	3
4	Downhole failure of drilling equipment	2	2	4	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
5	Accumulation of cuttings in borehole leading to equipment stuck in hole	2	2	4	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

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
6	HDPE duct stuck during pullback	2	2	4	Hole cleaning run(s) performed before pullback	1	2	2
					Installation forces monitored	1	2	2
					Safe pull limit adhered to	1	2	2
7	Breakout of drilling fluid to the surface during pilot drilling	2	2	4	Design with sufficient depth below surface for 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 and cutting size generated	2	2	4
					Topographical survey to identify risk of lateral fluid losses to cliffs	1	2	2
					Stopping point of pilot hole considers ground conditions found during pilot drilling	2	2	4
					Have Lost Circulation Materials available on site to seal any breakout	2	2	4
					Grouting if necessary	1	2	2
8	Collapse of granite blocks from roof of borehole	2	2	4	Ensure drilling equipment has ability to clear out collapsed blocks (hardfacing and gauge protection on rear)	2	2	4
					Geophysics to identify faults / shears	2	2	4
					HDD designed to drill in the most suitable ground conditions	2	2	4
					Grout any areas of instability downhole	1	2	2
9	Unthreading from downhole equipment during back reaming due to insufficient make-up torque applied to connections on barge / workboat / platform	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	2
					Use of cradles to assist in aligning drill rods	1	2	2
					Hydraulic breakout unit installed on barge / workboat	1	2	2

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
10	Breakout of drilling fluid to the surface 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 and cutting size generated	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
					Have Lost Circulation Materials available on site to seal any breakout	2	2	4
					Grouting if necessary	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	Collapse of installed water filled HDPE above MSL due to leak at exit end (tail) of duct	2	2	4	Provide for admittance of air to head after pullback is completed	1	2	2
					Check of potential vacuum forces to determine risk of ring collapse in duct	1	2	2
14	Duct sliding downhole after installation	2	2	4	Temporarily secure duct to rig anchor block after installation	1	2	2
					Grouting annulus between duct and borehole for length installed above sea level	1	2	2

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
15	Loose gravels and cobbles at exit point prevent or jam duct installation	2	2	4	Nearshore surveys to identify suitable exit points	1	2	2
					High volume flush from hole during initial duct pullback to prevent stones being dragged into borehole	1	2	2
					Clearing of sediment from around exit point	1	2	2
					Pushed duct installation	1	2	2
16	Drilling stopped due to nuisance noise / lighting to neighbouring residences or shipping (lighting)	2	2	4	Placement of topsoil stockpiles, office cabins etc as shielding	1	1	1
					Engines etc enclosed in silencing units	1	1	1
					Consultation with shipping authorities	1	1	1
					Pre construction baseline noise monitoring	1	1	1
					Installation of dedicated sound& light barriers if required	1	1	1
17	Collapse of coastal cliffs extending to work site	1	3	3	Position site and access sufficiently distant from cliff line	1	3	3
					Monitoring of nearby cliff for fretting and movement	1	3	3
18	Collapse of soft ground in superficial deposits at entry	2	1	2	Ensure drilling fluid characteristics are suitable for ground conditions (e.g. viscosity, fluid loss / filter cake)	1	2	2
					HDD designed to drill in the most suitable ground conditions	1	2	2
					Casing any unstable areas near entry or exit	1	2	2
					Excavate collapsed zones if sufficiently shallow	1	2	2
19	Parallel HDD boreholes accidentally intersect each other	1	2	2	Ensure guidance system has sufficient accuracy to avoid collision	1	1	1
					Grout and re-drill	1	2	2
20	Unintentional sliding downhole of unsecured drilling rods	1	2	2	Safety chain attached when tripping drilling rods in and out of initial section of borehole	1	2	2
					Rig personnel aware of risk and methodology	1	2	2
21	Construction affects local fauna – especially nesting birds	2	2	4	Programme to avoid sensitive seasons for wildlife	1	1	1
					Construction site sufficiently distant from wildlife sites	1	1	1

11. CONCLUSIONS AND RECOMMENDATIONS

11.1. Geology

The bedrock geology appears to be entirely Peterhead granite with wide joint spacing (0.5m to 3m) except in areas affected by fault / shear zones where the joint spacing parallel to the zone is generally 0.1m – 0.5m. These zones are generally near vertical with strikes (alignments) trending NNE-SSW, N-S or E-W. There is also a shallow north dipping synthetic fault exposed in the cliffs bounding the north of the site.

Exposures of faults / shear zones at the eastern edge of the site show them to be foliated and more weathered than surrounding rock. There were no apparent veining, slickensides, open fractures, or clay infilled fractures. No water was noted flowing from the zones but they were a route for surface water because they have weathered to form gullies. The indication is that they would not be a route for bentonite breakout.

The Gutter of Nesh off the eastern end of the site appears to follow a fault / shear zone. The weathering along this zone is potentially deeper and of higher grade than the observed zones resulting in it eroding to form the bathymetric feature.

The granite is likely to be of very high strength, probably around 200MPa and will be slow to drill but should form a stable borehole. Where the borehole passes through faults or shear zones there is the potential for local collapse of blocks from the roof of the borehole if the orientation of close spaced jointing is unfavourable. However the collapse volume should be limited by arching around the 762mm diameter borehole.

The superficial deposits at the drill site appear to be composed of a thin (0.5m) layer of humus overlying silty sand with gravels, 1-3m in thickness. The proportion of gravel appears to increase with depth and near the base of the superficials there are likely to be cobbles, possibly boulders, of granite corestone.

The seabed sediments at exit point are expected to be 1m to 3m of glacial till overlain by 4m to 5m of dense sand and 1m to 1.5m of loose gravelly sand or loose silt and fine sand.

11.2. Feasibility of the proposed HDD design

Based on the available information the use of a landfall drilled by HDD from the site is feasible. There are no indications of any ground conditions that would cause significant risk of non-completion by HDD.

The initial Rev00 feasibility report examined designs along two separate alignments; a Northern Alignment drilled towards bearing 070° (OS Grid) and a Southern Alignment drilled towards 120° (OS Grid). The entry point for both Alignments was in a similar area on a gently sloping section of the field approximately 100m back from the eastern edge of the field.

This update to the feasibility report, Rev01, discounted the northern alignment and produced three conceptual designs exiting at a similar position to the southern alignment. Based on discussions during the second site visit, the entry points for the HDD was moved to higher ground approximately 90m SSW of the Rev00 HDD entry site. This area of higher ground offers simpler access and a larger area in which to site the HDD’s, with more level ground.

Following onshore ground investigations the preferred alignment of Southern Design 5 has been examined in this Revision 2 of the feasibility report. The design is shown in plan and section view in shown in Appendix E, drawing number 20160401RA-C/07.

The designs is 409.10m in length, with entry elevation approximately +38m ODN and exit elevation -28m ODN (26m below LAT). The entry angle is 17° in order to maximise the depth beneath the coastal land; it is at the upper end of normal HDD rig setup angles.

A cable landfall for the Hywind project was successfully drilled through Peterhead granite for the Hywind project in August 2016. The HDD drilling contractor was LMR drilling and by their account the drilling and installation was relatively straightforward. They noted variable strength in the granite that suggests a number of weathered zones, similar to those described in the power station tunnel construction (Edmond, 1977), were encountered. There were no indications that the weathered zones created borehole instability.

Weathered zones on this project might be expected from MHWS onwards, and therefore over the final 200m of the HDD. The angled ground investigation boreholes were positioned to test the potential extension of a fractured or weathered zone that caused the “pond” area on the coastline just to the north of the HDD alignments. In BH202 a weak zone was encountered at 36.1m to 37.6m depth that aligns with this feature. While total core recovery was 100% in this zone, Solid core recovery was 0% and Rock Quality Designation was 0% indicating very broken ground. Flush returns, however, were 100% in this zone indicating that the fault is of low permeability and should be sealed by the drilling fluid.

The HDD entry point for the Hywind project was located in Barclay Park, Peterhead, with the HDD 660m in length and 610mm diameter. The elevation of the entry point was approximately 15m AOD and the exit was at -14m. The entry point for this project is considerably higher (approximately 38m AOD). This results in a longer section of borehole that is unsupported by drilling fluid when the HDD exits to the sea. Ground investigation boreholes will provide further information of the risk of ground collapse in this length. Based on observations of the stability of the surrounding cliffs, even in areas where jointing and faulting patterns intersect, ground collapse is expected to be a low risk to successful completion of the HDD.

The marine operations for the Hywind landfall were planned to use a multi-cat vessel anchored at the exit point and used as support vessel during the breakthrough and diving operations. This suggests the HDD was forward reamed for most of the length. The duct installation was planned as a floated duct using two tugs for the duct and a support vessel and divers for connection to the pulling assembly.

11.3. Primary Geotechnical Risks

11.3.1 Drilling Fluid Breakout

Hydrofracture modelling indicates that the conceptual design has a low risk of (vertical) breakout until the final 30m to 40m before exit. For breakout to occur within the granite it would require a vertical fracture of 10mm or wider infilled with soft clay. Any fractures/ joint gaps seen on the site visit were 2mm or less on the rock exposures.

The greatest risk of breakout in the granite is from lateral or downward migration of fluid to adjacent cliffs when the HDD is above sea level. The design is potentially only 30m from cliffs to the south and loss of drilling fluid to them, although unlikely, is a possibility.

The next highest probability of inadvertent breakout will be within 40m of the exit. When the HDD exits the granite, at approximately 43m before the seafloor exit point for Southern Design 5, the risk of breakout to the seafloor significantly increases. The selection of the point at which to stop the pilot hole drilling and commence forward reaming will need to assess this risk using information from the nearshore surveys and monitoring of conditions during the drilling.

When forward reaming has been completed there is an unavoidable loss of drilling fluid as the pilot hole exits to the sea. Any fluid above sea level at the entry side (approximately 110m of drilled length) will flow into the sea. The volume of fluid will be approximately $38m^3$ per HDD for this stage of losses.

Following the exit to the sea floor the HDD might need to be pull reamed to open up the last section of borehole to 30” diameter. The volume of fluid required for this phase, and lost to the sea, will depend on the length to be reamed and the nature of the rock. Indicative fluid volumes lost to the sea are provided in Section 11.6.

The final unavoidable release of drilling fluid will occur during duct installation when the duct displaces its volume of drilling fluid from the bore. For the Southern Design 5 HDD this will be approximately $70m^3$ per HDD.

While bentonite is a naturally occurring clay and breaks down in saline water, consideration will need to be given to the potential environmental and visual effects of this release. These unavoidable releases occur on all HDD landfalls; early discussions with the relevant authorities (SEPA etc) are always advisable.

11.3.2 Ground Collapse

There is a risk of ground collapse in the superficial near the entry point, particularly once the pilot hole exits to the sea and the support of the drilling fluid is lost. However, this is not expected to be a significant problem; at worst it would require temporary 34” steel casing for the likely 20m length drilled in the silty sands, cobbles and boulders.

When the HDD passes through fault or shear zones there is the potential for local collapse of blocks from the roof of the borehole. This would occur if the orientation of close spaced jointing is unfavourable, however the collapse volume should be limited by arching around the 560mm diameter borehole. To mitigate the risk the drilling contractor should be diligent in monitoring drilling forces, proactive in hole cleaning, and their drilling tools should enable some degree of protection against working back through collapsed blocks.

At the exit point the nearshore survey will need to assess the thickness and type of sediment to mitigate the risk of gravels and cobbles being dragged into the borehole during duct installation. This potentially could result in the duct becoming stuck.

11.4. HDD Rig and Drilling Equipment

A HDD rig with 70 tonne pull force or greater is recommended; most contractors would elect to use a 100t machine or larger to ensure sufficient power for the reaming stages. The critical parameter is not likely to be the pull / push force but the torque capability of the machine; a rig with 34 kN.m or more should be considered and this is likely to mean a rig of 70t pull force or greater.

11.5. Guidance

A wireline guidance system will be almost certainly used to allow monitoring and surveying of the HDD from the driller’s cabin. The guidance tool is located a few metres behind the downhole motor and sends real time information back to the drillers cabin through a cable inside the drilling rods.

The two main options for a wireline system are a Gyro system or a Magnetic Guidance System (MGS). Either system is suitable for the project.

The MGS will have additional surface tracking capability to calibrate the magnetic bearing of the HDD (proprietary names include Tensor and Paratrack). The surface tracking requires a thin (4mm diameter) cable to be placed at surface along a section of the drilling route. In this case it would likely extend to the edge of the grassed area above the bare coastal rocks.

11.6. Drilling Fluid

Drilling fluid tailored to the ground conditions is an important part of the HDD process for both completing the HDD efficiently and minimising the risk of breakout. The HDD contractor should use a reputable mud (drilling fluids) engineer and quality products to ensure the borehole is stable, that all cuttings are carried from the borehole and the friction in the borehole is minimised.

On some landfall HDD’s a proprietary drilling fluid called Purebore is used for the exit and pull reaming. Purebore is CEFAS registered and biodegradable but incurs additional costs and requires an additional number of shifts to mix and displace the existing bentonite fluid in the borehole.

There will be unavoidable losses to the sea at three stages of the HDD:

1. When the pilot hole exits at the seafloor. At this point all the fluid in the length of HDD above sea level will flow out until the fluid level in the HDD is at sea level.
2. During pull reaming of the final section of HDD. The last 50m to 70m of HDD might be pull reamed – the reamer is pulled from exit toward entry with fluid flowing to the exit point. The volume of fluid depends on the drilling time (related to how hard the ground is). The volume of solids depends on the volume of hole to be reamed.
3. During duct installation the duct will displace drilling fluid from the hole.

Table 9 below provides indicative volumes for fluid loss on the Rev01 report HDD designs.

Table 9. Estimated drilling fluid volumes lost to the sea for a single HDD on Southern Design 5.

ESTIMATED DRILLING FLUID LOSSESS FOR HDD DESIGN OPTIONS FOR A SINGLE HDD			
PROJECT: NorthConnect		DATE: 13th May 2018	
Duct Diameter	400	mm	
Working hrs / shift	12	hrs	
Av. Drilling Time per shift	6.0	hrs	
Mud capacity	1.75%	% solids	

REAMING VOLUMES	Diameter of stage	Volumes	
		Bore	Cut
	(inches)	(m^3 / m)	(m^3 / m)
Pilot	12.25	0.08	0.08
Ream 1	18	0.16	0.09
Ream 2	24	0.29	0.13
Ream 3	30	0.46	0.29

HDD	Southern HDD Design No.	5	Units
	Total HDD length	415	m
	Length of HDD above MSL	130	m
Pilot & Fwd Ream Stopping Points	Pilot	65	m before exit
	Ream 1	70	m before exit
	Ream 2	75	m before exit
Granite drilled with losses to sea	Ream 1	27	m of granite
	Ream 2	32	m of granite
Superficial drilled with losses to sea	Ream 1	43	m of superficials
	Ream 2	43	m of superficials
DRILLING FLUID LOSSES TO SEA	Loss 1 on pilot hole exit (fluid)	38	m^3 (volume above MSL)
	Loss 1 on pilot hole exit (solids)	0.7	m^3
	Loss 2 during reaming (fluid)	881	m^3 total
	Shifts Reaming	2.5	shifts
	Loss 2 per shift (fluids)	346	m^3/shift
	Loss 2 per shift (solids)	4.9	m^3/shift
	Loss 3 on pullback (fluids)	70	m^3
	Loss 3 on pullback (solids)	0.2	m^3
TOTAL LOSSES TO SEA	FLUIDS	989	m^3
	SOLIDS	5.8	m^3

11.7. Noise and Lighting

The nearest residences are 500m and 700m from the HDD site. Noise is unlikely to adversely affect these neighbours except during night working in summer when a light breeze is blowing towards the residences.

Site lighting for 24 hr working is unlikely to be an issue for residences but may require consultation with Peterhead Port Authority to ensure it doesn't affect shipping navigation.

11.8. Duct Installation Method

There are two options for installation of the duct, a pulled installation using a floated duct at the exit point, and a pushed installation using a duct pushed into the HDD from the land. Pulled installations are the conventional method of installation for landfalls.

Pushed installations potentially offer the advantage of reduced offshore works. However, if additional PE pipelines for grouting of the borehole are to be installed with the main duct some form of marine support might be required to provide tension at the head of the duct.

Both pushed and pulled installation are potential options at the location and it is recommended that the choice of methodology is given to the HDD contractor if possible. The pushed installation requires a stringing area for the pipeline; this can be undertaken along the land cable route, provided that this section of cable installation is not scheduled at the same time as HDD works.

11.9. Installation Forces

The modelled installation (pullback) forces for a conventional pulled installation are well within the limits of a 650mm SDR9 PE100 duct provided the duct is water filled and well within the likely capabilities of the HDD rig.

11.10. Trenchless Crossing of the A90 and Abandoned Railway

During the second site visit the potential location of trenchless crossing of the A90 and abandoned railway was visited. The location is described in Section 2.2.2. The locations could be undertaken as separate crossings or as a single crossing.

For a single crossing, the HDD method would be required, other trenchless techniques are unlikely to be feasible or economic over this length. The crossing would be approximately 120m in length and would probably require a midi sized HDD rig (capable of 15t to 40t pulling force).

The cable route is expected to cross the road and railway at an oblique angle of approximately 70 degrees; this is not expected to be a problem for permitting by Transport Scotland. The depth of any HDD will need to be optimised to ensure that any surface settlement at the A90 is acceptable to Transport Scotland. As a guide, a depth of 7m has been used on similar HDD crossings of the A90 in superficial deposits, but the depth will depend on ground conditions and Transport Scotland requirements.

If undertaken as separate crossings, HDD or alternative trenchless methods such as auger bore and pipe ramming could be used. The A90 crossing would be approximately 40m in length, the railway crossing 20m. If completed as HDD’s a mini-HDD rig (less than 15t pull force) could be suitable, however the depth of the design beneath the A90 would still need to satisfy Transport Scotland.

For the A90 crossings non-HDD methods would allow a shallower depth of cover because the maximum amount of settlement from these methods in superficial deposits is lower. However, the appropriate technique will depend on ground conditions and in the case of shallow bedrock, HDD is likely to be preferred over other trenchless methods.

It is recommended that the working corridor between the A90 and railway is maintained at normal widths (typically 30m) so that the contractor can choose the most suitable method for the crossings. Parallel HDD’s can be drilled at 2m centres if required, 3m centres is more commonly used, subject to suitability for thermal dissipation. Alternative trenchless methods can use similar spacings or might consider using a larger pipe with two ducts installed within it, subject to suitability for thermal dissipation.

Figure 27 below shows a typical layout for a midi sized HDD that would probably be used for the crossing (about 120m length). The area shown on the pdf is 25m x 30m. It might be better to allow

30m x 30m on the northern side of the A90, set back 15m from the road. On the southern side of the A90 an area of 20m x 20m would be suitable for the exit area. Normally the crossing would be drilled as two separate HDD's, one with cable duct and fibre optic duct and a second with just a cable duct. Separation distance between the HDD's is typically 5m for this length HDD.

An outline methodology for completing a HDD crossing with a midi HDD rig is provided in Appendix D of this report. Conceptual Designs for crossing both the A90 and abandoned railway using maxi and mini rigs are provided in Appendix E, Drawing No's 20160401RA-C/31 and 20160401RA-C/32.

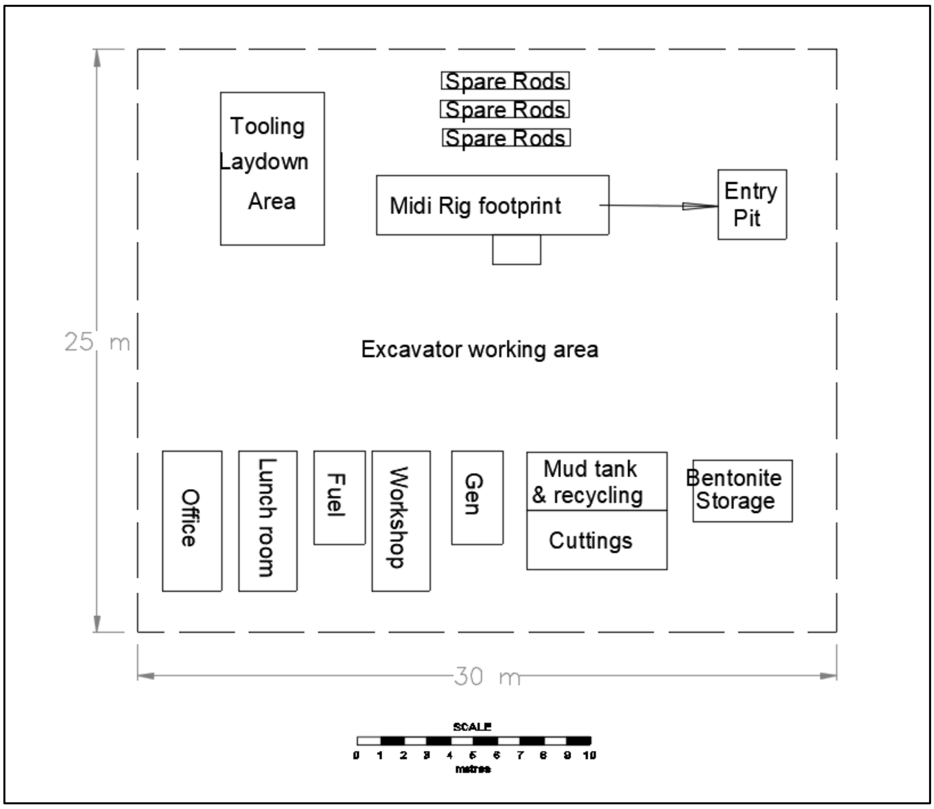

Figure 27. Indicative layout for a midi sized HDD rig.

12. REFERENCES

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Edmond, J.M. and Graham, J.D.. 1977. "Peterhead power station cooling water intake tunnel: an engineering case study". *Quarterly Journal of Engineering Geology* 10, pp281–301.

Hall, A.M., "Hill of Longahven Quarry". *Geological Conservation Review, Volume 6: Quaternary of Scotland, Chapter 8: North-east Scotland, Site: Hill of Longahven Quarry (GCR ID: 374).* Accessed from http://jncc.defra.gov.uk/pdf/gcrdb/GCRsiteaccount374.pdf on 12th May 2016.

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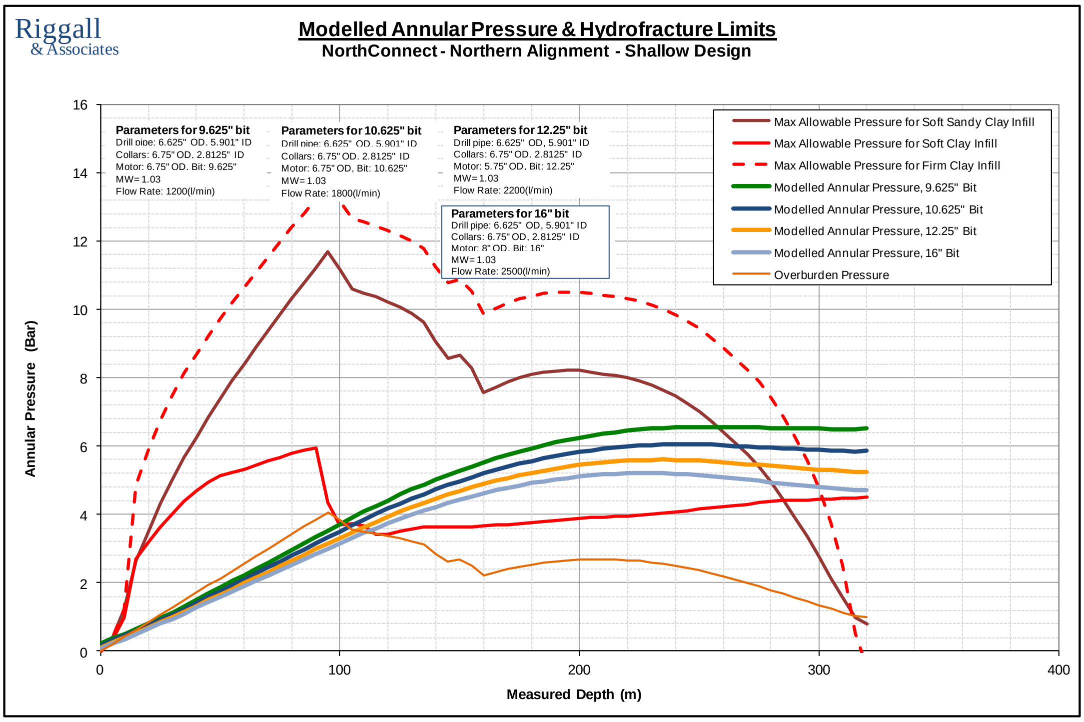
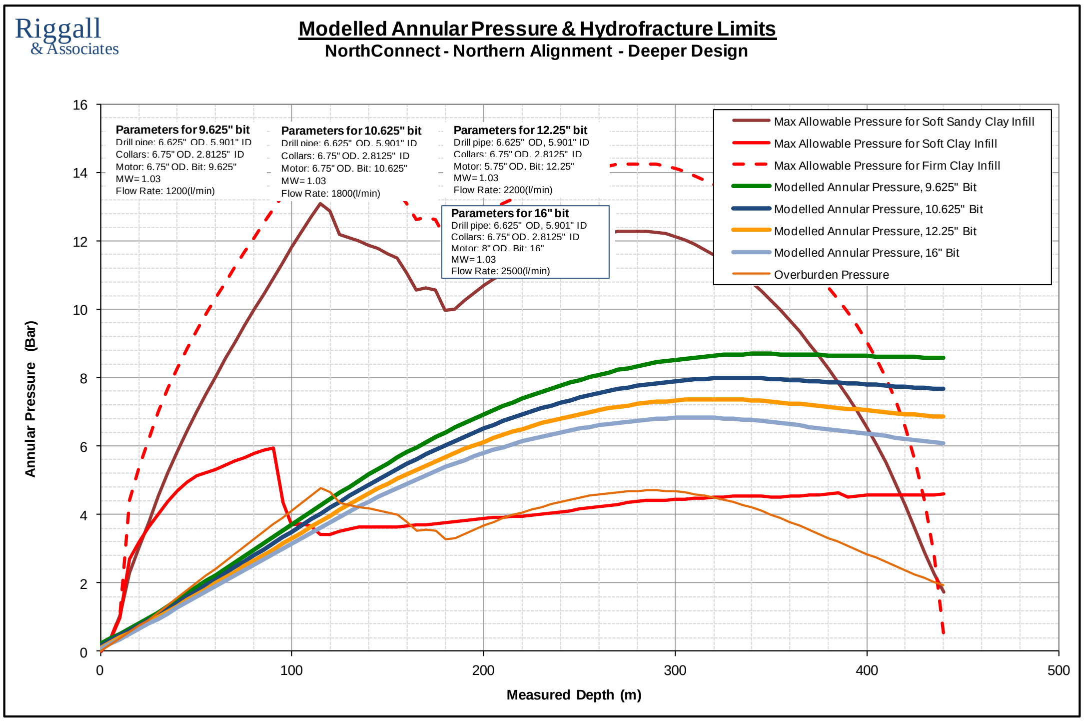
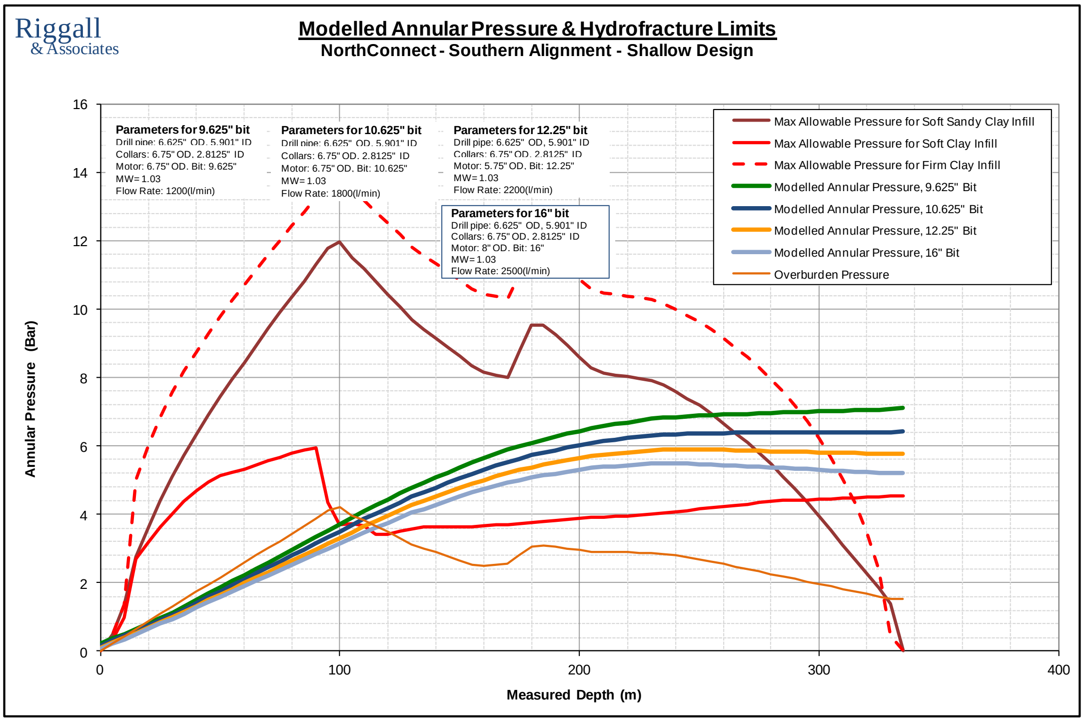
APPENDIX A Output graphs from hydraulic fracture modelling



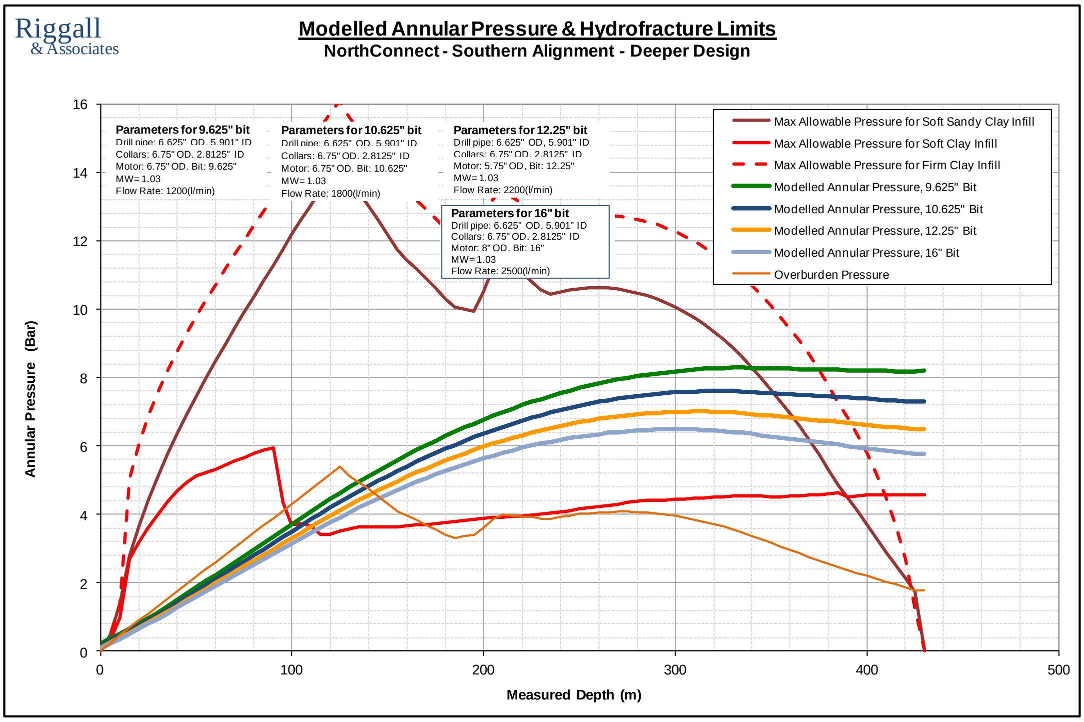
North Alignment, shallow design. Breakout at surface is unlikely until 20-30m before exit and would require a substantial (>20mm) infilled shear / fault / joint.



North Alignment, deeper design. Breakout at surface is unlikely until 20-35m before exit and would require a substantial (>20mm) infilled shear / fault / joint.

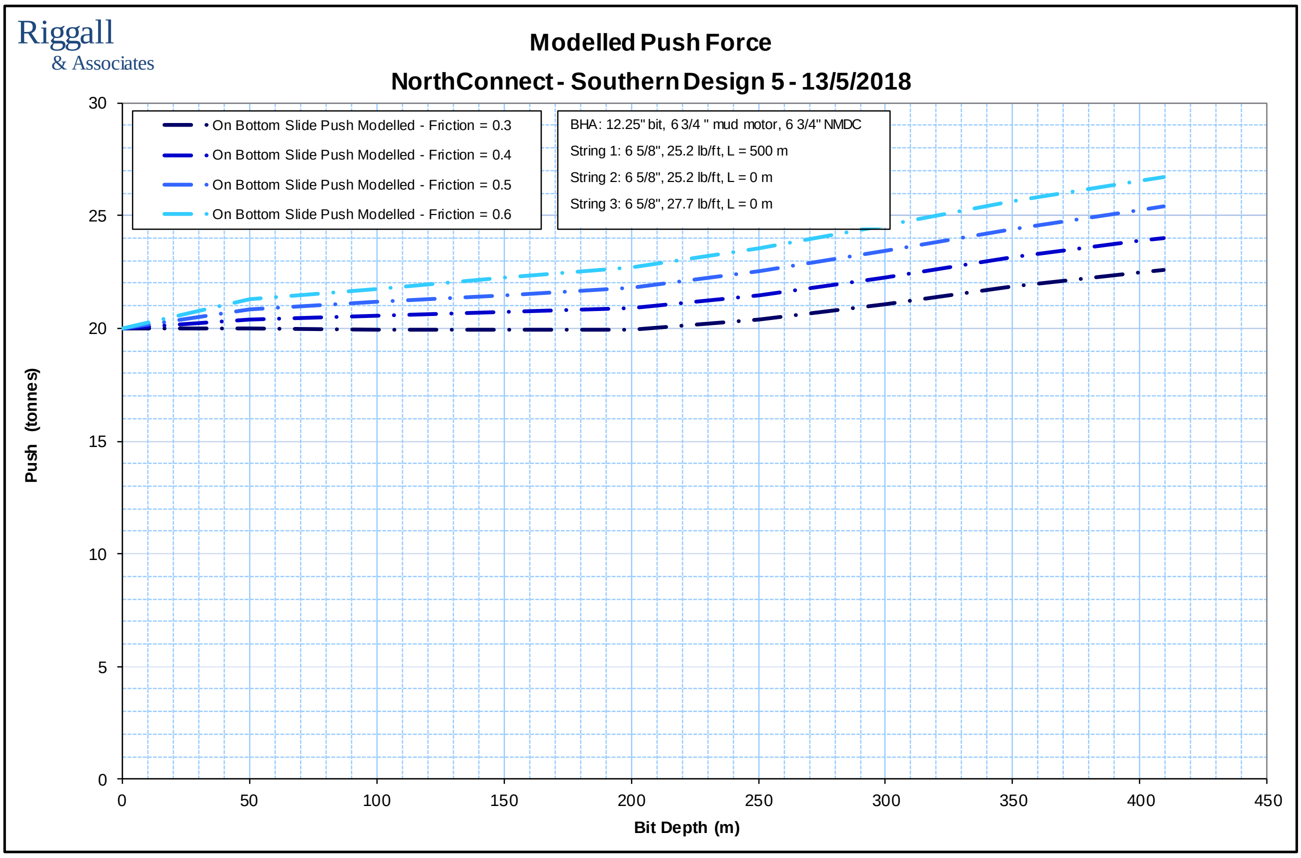


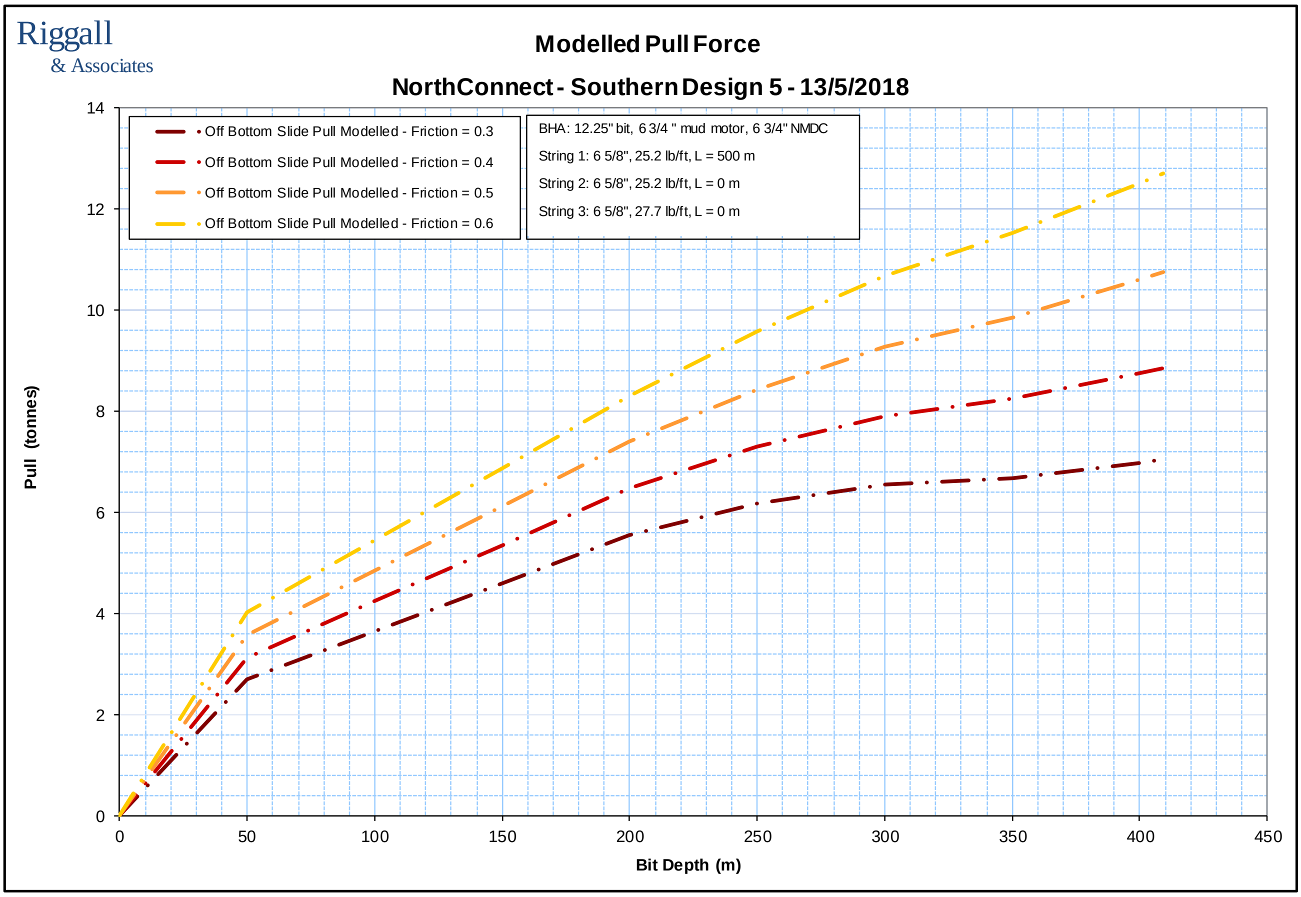
South Alignment, shallow design. Breakout at surface is unlikely until 25-45m before exit and would require a substantial (>20mm) infilled shear / fault / joint. The increased distance before exit for this design is due to the shallower exit angle, +3° as opposed to +5° for the other three designs.

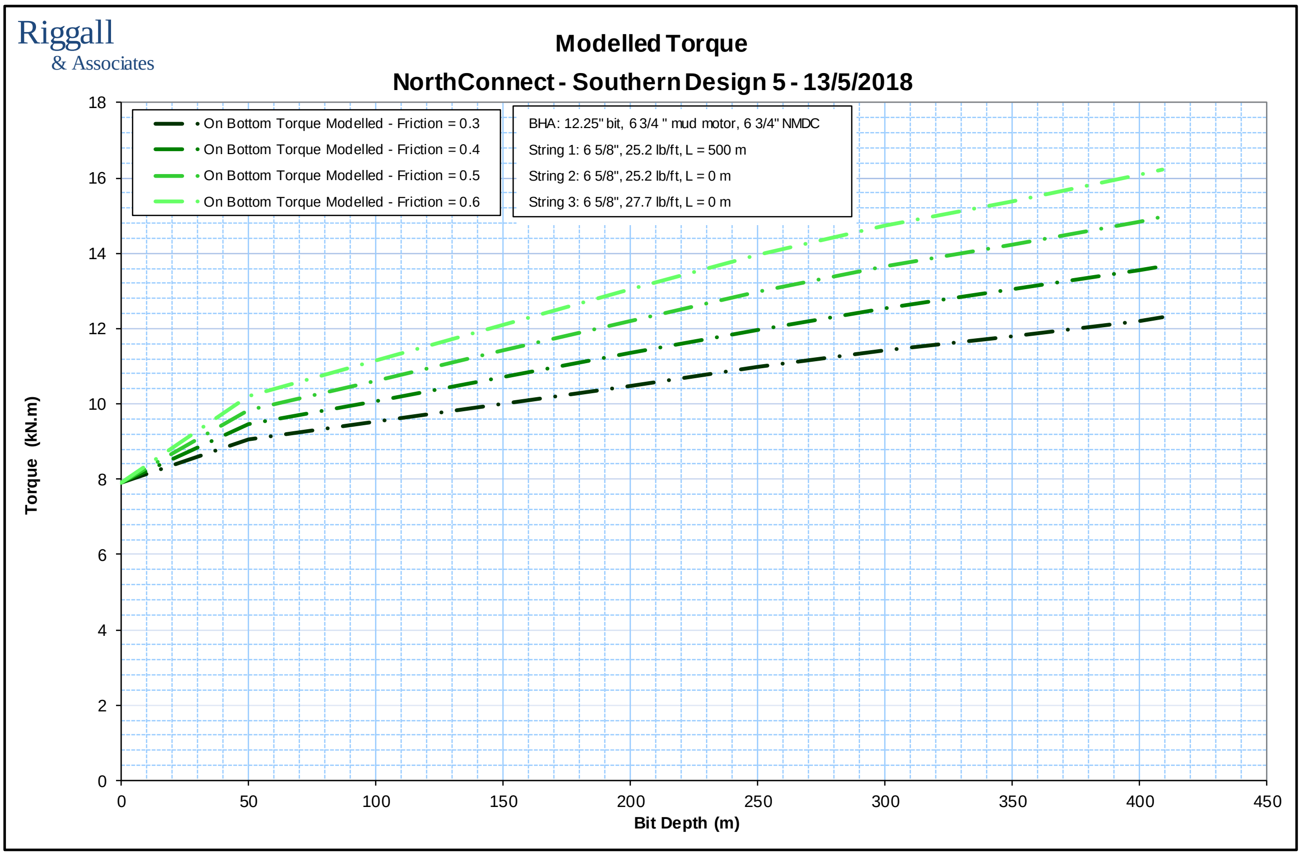


South Alignment, deeper design. Breakout at surface is unlikely until 20-40m before exit and would require a substantial (>20mm) infilled shear / fault / joint.

APPENDIX B Output graphs from modelling of Drilling Forces



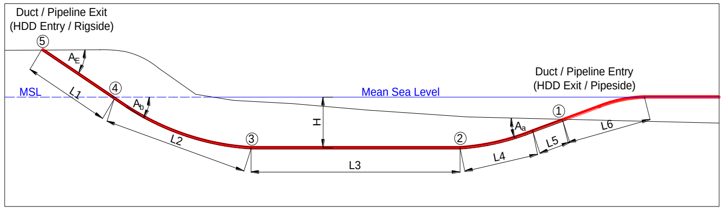



Riggall
& Associates
Modelled Torque
NorthConnect - Southern Design 5 - 13/5/2018
On Bottom Torque Modelled - Friction = 0.3
On Bottom Torque Modelled - Friction = 0.4
On Bottom Torque Modelled - Friction = 0.5
On Bottom Torque Modelled - Friction = 0.6
BHA: 12.25" bit, 6 3/4 " mud motor, 6 3/4" NMDC
String 1: 6 5/8", 25.2 lb/ft, L = 500 m
String 2: 6 5/8", 25.2 lb/ft, L = 0 m
String 3: 6 5/8", 27.7 lb/ft, L = 0 m
Torque (kN.m)
Bit Depth (m)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
250
300
350
400
450

APPENDIX C Output from Calculation of Duct Pullback Forces

PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, EMPTY PIPE
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: **NorthConnect - Design 5**
Modelling Date: **13th May 2018**



Pipe specifications and Borehole dimensions				
Reamed hole diameter	D_H	30	Inches	762 mm
Pipe outer diameter	OD	560	mm	22.0 inches
SDR		9		
Wall thickness	t	62 mm		2.4 inches
Pipe internal diameter	ID	436 mm		17.1 inches
Reamed : Pipe ratio		1.36 (1.5 typical)		
Density	HDPE	0.952 t/m3		0.034 lbf/in^3
Cross sectional area		97304 sq mm		151 sq inches
Design minimum radius	R_{min}	400 m		1312 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	132.34 m	
Angle	A_E	17 deg	
Section of borehole below Mean Sea Level (MSL)			
As drilled exit angle (pipeside)	A_a	5 deg	0.087 rad
Angle (rigside) at MSL	A_b	17 deg	0.297 rad
Drilled MSL tangent + curve length	L_2	179.40 m	588.6 ft
Horizontal tangent length	L_3	0 m	0.0 ft
Drilled exit curve length	L_4	35.39 m	116.1 ft
Exit tangent	L_5	63.69 m	209.0 ft
Vertical depth (relative to MSL)	H	35.19 m	115.5 ft
Length from exit to sea level (MSL)	L_6	81.5 m	267.4 ft

Minimum radius		
Minimum Installed Radius	34	m
Minimum overbend radius	22	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	0.093	tonnes/m	62	lb/ft
Buoyant empty weight, W_b	-0.178	tonnes/m	120	lb/ft ^
Buoyant filled weight, W_b	-0.029	tonnes/m	20	lb/ft ^
Total pipe length	278	m		
Total pipe weight	26	tonnes	56,752	lbs
Total pipe weight submerged	-50	tonnes	- 109,235	lbs
Total pipe weight of submerged tail in sea	-14	tonnes	- 29,852	lbs

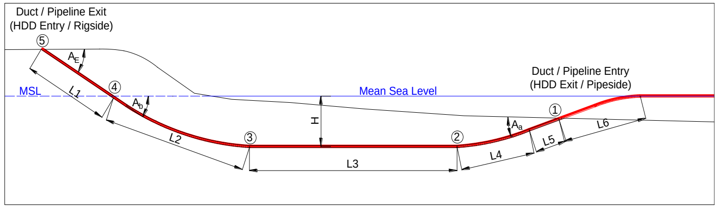
PULLBACK FORCES		
Combined Drag and Capstan Forces at:		
Point 1	15 t	32,708 lbs
Point 2	35 t	78,045 lbs
Point 3	48 t	106,562 lbs
Point 4	52 t	114,928 lbs
Hydrokinetic Force	0.5 t	990 lbs
Max Force from submerged section	52.7 t	115,919 lbs

Gravitational pull component	3.6 t	7,902 lbs
Frictional pull component	4.7 t	10,338 lbs
Pipe unlikley to slide downhole if unsecured		
Force from dry section (empty pipe)	8.3 t	18,240 lbs

Maximum force through submerged hole	52.7 t	116,162 lbs
Maximum force through dry hole	8.3 t	18,240 lbs
Maximum Force	61.0 t	134,402 lbs

PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, FRESH WATER FILLED PIPE
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: **NorthConnect - Design 5**
Modelling Date: **13th May 2018**



Pipe specifications and Borehole dimensions					
Reamed hole diameter	D_H	30	inches	762	mm
Pipe outer diameter	OD	560	mm	22.0	inches
SDR		9			
Wall thickness	t	62	mm	2.4	inches
Pipe internal diameter	ID	436	mm	17.1	inches
Reamed : Pipe ratio		1.36	(1.5 typical)		
Density	HDPE	0.952	t/m3	0.034	lbf/in^3
Cross sectional area		97304	sq mm	151	sq inches
Design minimum radius	R_{min}	400	m	1312	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	132.34	m		
Angle	A_E	17	deg		
Section of borehole below Mean Sea Level (MSL)					
As drilled exit angle (pipeside)	A_a	5	deg	0.087	rad
Angle (rigside) at MSL	A_b	17	deg	0.297	rad
Drilled MSL tangent + curve length	L_2	179.40	m	588.6	ft
Horizontal tangent length	L_3	0	m	0.0	ft
Drilled exit curve length	L_4	35.39	m	116.1	ft
Exit tangent	L_5	63.69	m	209.0	ft
Vertical depth (relative to MSL)	H	35.19	m	115.5	ft
Length from exit to sea level (MSL)	L_6	81.5	m	267.4	ft

Minimum radius		
Minimum Installed Radius	34	m
Minimum overbend radius	22	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	0.093	tonnes/m		62	lb/ft
Pipe weight filled, W_{pw}	0.242	tonnes/m		162	lb/ft
Buoyant empty weight, W_b	-0.178	tonnes/m		120	lb/ft ^
Buoyant filled weight, W_b	-0.029	tonnes/m		20	lb/ft ^
Total pipe length	278	m			
Total pipe weight	26	tonnes		56,752	lbs
Total pipe weight submerged	-8	tonnes	-	17,951	lbs
Total pipe weight of submerged tail in sea	-2	tonnes	-	4,906	lbs

PULLBACK FORCES				
Combined Drag and Capstan Forces at:				
Point 1	3.5	t	7,762	lbs
Point 2	7.0	t	15,297	lbs
Point 3	8.9	t	19,669	lbs
Point 4	9.4	t	20,680	lbs
Point 5	31.4	t	69,294	lbs
Hydrokinetic Force	0.5	t	990	lbs
Max Force from submerged section	9.8	t	21,670	lbs

Gravitational pull component	9.3	t	20,612	lbs
Frictional pull component	12.2	t	26,967	lbs
Pipe unlikley to slide downhole if unsecured				
Force from dry section of hole (full)	21.6	t	47,579	lbs

Maximum Force	31.4	t	69,294	lbs

PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, SEA WATER FILLED PIPE

Simple outfall model for air filled pipe. Assumes water level in HDD is at MSL.

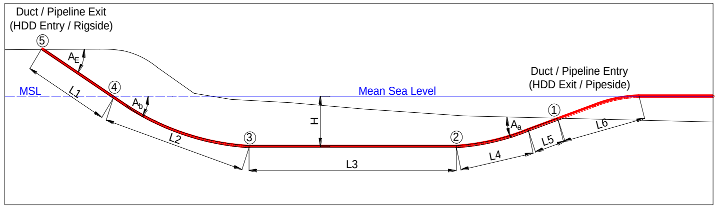
Assumes pipe is floating in sea and pulled in by HDD rig on land.

Base on method by Slavin as outlined by Plastic Pipes Institute

Includes Frictional Drag Forces, Capstan Forces, and Hydokinetic Forces

Project: **NorthConnect - Design 5**

Modelling Date: **13th May 2018**



Pipe specifications and Borehole dimensions					
Reamed hole diameter	D_H	24	inches	762	mm
Pipe outer diameter	OD	450	mm	22.0	inches
SDR		9			
Wall thickness	t	62	mm	2.4	inches
Pipe internal diameter	ID	436	mm	17.1	inches
Reamed : Pipe ratio		1.36	(1.5 typical)		
Density	HDPE	0.952	t/m3	0.034	lbf/in^3
Cross sectional area		97304	sq mm	151	sq inches
Design minimum radius	R_{min}	400	m	1312	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	132.34	m		
Angle	A_E	17	deg		
Section of borehole below Mean Sea Level (MSL)					
As drilled exit angle (pipeside)	A_a	5	deg	0.087	rad
Angle (rigside) at MSL	A_b	17	deg	0.297	rad
Drilled MSL tangent + curve length	L_2	179.4	m	588.6	ft
Horizontal tangent length	L_3	0	m	0.0	ft
Drilled exit curve length	L_4	35.39	m	116.1	ft
Exit tangent	L_5	63.69	m	209.0	ft
Vertical depth (relative to MSL)	H	35.19	m	115.5	ft
Length from exit to sea level (MSL)	L_6	81.5	m	267.4	ft

Minimum radius		
Minimum Installed Radius	34	m
Minimum overbend radius	22	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	0.093	tonnes/m		62	lb/ft
Pipe weight filled, W_{pw}	0.245	tonnes/m		165	lb/ft
Buoyant empty weight, W_b	-0.178	tonnes/m		120	lb/ft ^
Buoyant filled weight, W_s	-0.026	tonnes/m		17	lb/ft ^
Total pipe length	278	m			
Total pipe weight	26	tonnes		56,752	lbs
Total pipe weight submerged	-7	tonnes	-	15,669	lbs
Total pipe weight of submerged tail in sea	-2	tonnes	-	4,282	lbs

PULLBACK FORCES				
Combined Drag and Capstan Forces at:				
Point 1	3.2	t	7,138	lbs
Point 2	6.2	t	13,728	lbs
Point 3	8.0	t	17,497	lbs
Point 4	8.3	t	18,323	lbs
Point 5	30.7	t	67,666	lbs
Hydrokinetic Force	0.5	t	990	lbs
Max Force from submerged section	8.8	t	19,314	lbs

Gravitational pull component	9.5	t	20,929	lbs
Frictional pull component	12.4	t	27,383	lbs
Pipe unlikley to slide downhole if unsecured				
Force from dry section of hole (full)	21.9	t	48,312	lbs

Maximum Force	30.7	t	67,666	lbs

APPENDIX D Outline Methodology for a Midi-HDD Rig Crossing

The following is an indicative methodology for a crossing using a Midi HDD rig (15t-40t pull capability). A detailed methodology will need to be tailored to suit the circumstances of individual crossings.

Site Setup

Prior to arrival of HDD equipment the vehicle access, drilling pad and working area at the entry site will 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.

Once the topsoil has been stripped bog mats or geotextile with hard standing material might be used to ensure a suitable surface.

Overhead power lines will require transport planning to be negotiated safely, some of them might require safety goalposts to be installed.

Any drainage work required to make the site safe for working and to prevent environmental damage through contaminated runoff should be completed before mobilisation of HDD equipment.

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. Because of the length and relatively small diameter of the HDD's, mains water could be tankered to site with a tractor and bowser or obtained from the nearest mains water from a hydrant point.

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

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 used.

Usually the drilling rig will use its own auger screw anchors to stabilise the rig while drilling. In some cases sheet piling might be require at the front of the rig to ensure stability when drilling and installing the pipeline. Sheet piles are usually 4m or longer across a 3-4m width with I beams welded or bolted to the top for connection to the HDD rig.

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, 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 commencement of drilling barrier mesh 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.

Noise generated by the works is not usually a nuisance to nearby residents during the day. For mini and midi rigs the noise is comparable to excavators and working is only likely to be during daylight hours.

Pilot Hole

Prior to the drill commencing 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.

Pilot hole drilling normally uses either a jetting assembly (Figure 18) on crossings without rock. Where crossings are expected to drill into bedrock a tri-cone drilling bit powered by a downhole motor (DHM) will be used.

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 or bent sub is oriented and then pushed forwards to steer in the required direction. When using a tri-cone bit the function of the jetted fluid is more to clear away the cuttings than to hydraulically excavate the ground ahead.

A DHM uses the hydraulic pressure of the drilling fluid to turn a progressing cavity motor located behind the bit. Like a jetting assembly a DHM has a bend section to allow the hole to be steered. To steer the bend is oriented in the required direction and the drilling rods are pushed in without rotation. Only the drilling bit, powered by the DHM, is rotating to cut the rock and advance the bore. For drilling straight sections of hole the entire drillstring is rotated.

Behind the jetting assembly or DHM will be the guidance probe followed by the drilling rods. Between the components there may be various connection subs to provide connections between differing types and sizes of threads. All connections are torqued to recommended values as they are added at the drilling rig.

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.

To ensure the HDD follows the designed route either a walkover system or a wireline system will be used to track and steer the HDD. A walkover system uses a battery powered transmitter behind the drilling bit. The signals are received at surface using a walkover detector that allows the position and orientation of the drilling head to be determined. Walkover systems are typically effective to a depth of 15m and possibly 20m below surface.

Figure 28. Example a midi sized HDD rig. The rig is anchored with sheet piling in this case.

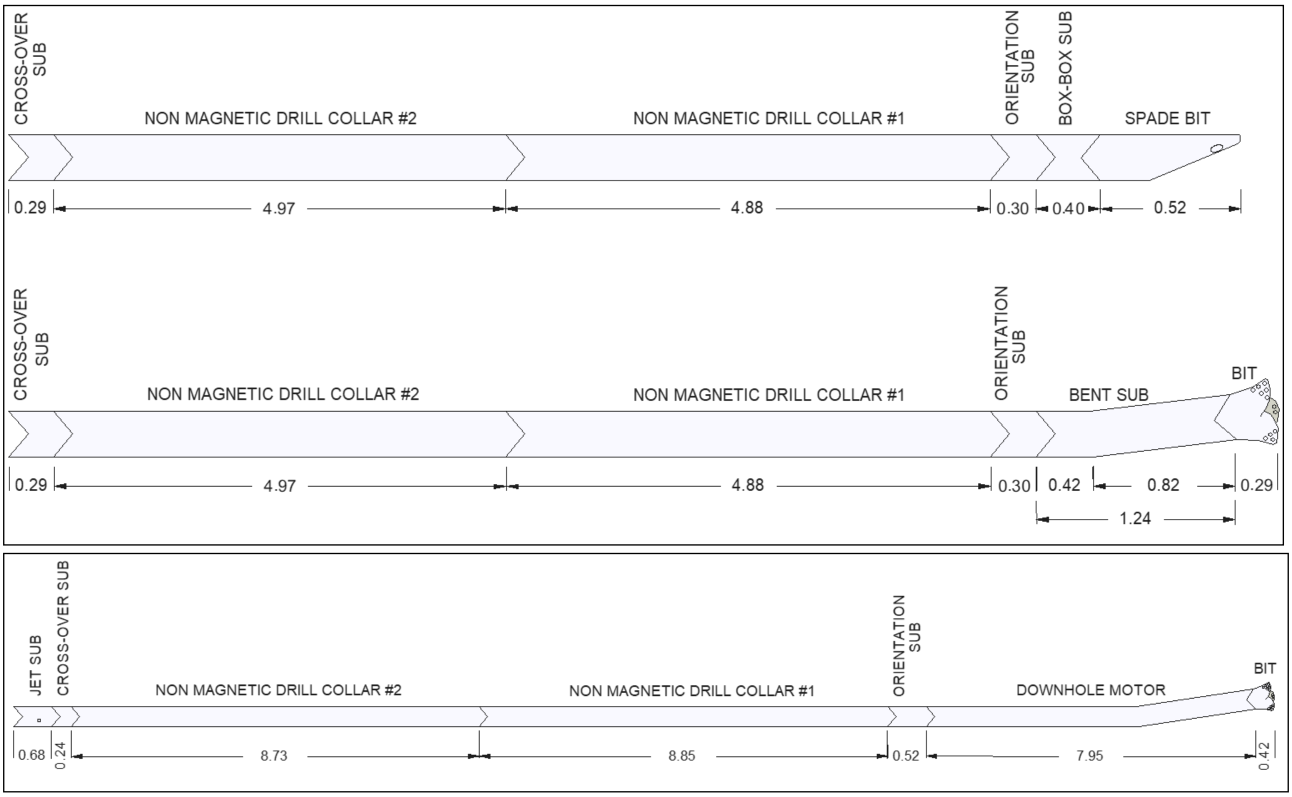


Figure 29. Example drilling assemblies; Jetting assembly with spade bit at top, jetting assembly with tri-cone bit in centre, and downhole motor assembly with tri-cone bit at bottom.

A wireline steering tool uses guidance sensors located behind the drilling bit or downhole motor that send and receive data through a wireline running through the centre of the drill rods. Equipment at the surface collects the data and gives real time information on position and orientation of the HDD. There are two standard wireline systems, Magnetic Guidance System (MGS), often with additional surface tracking, and the Gyro System.

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.

During drilling operations the drilling rods will be turning at around 60-90 rpm. All personnel should stand clear of the rotating rods. 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.

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. A wireline cable inside the drilling rods is extended and connected before the new rod is torqued ready for drilling down.

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 some drilling rigs 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 rods 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.

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, 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 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. Standard bentonite fluid breaks down quickly (flocculates) in seawater. Varieties of bentonite are available that are stable in saline water, however their effectiveness is less than normal freshwater mixes.

Bentonite is supplied in powdered form in either 25kg bags or 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 30. Drilling Fluid (“Mud”) Recycling Unit for midi sized HD rig.

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 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 that any losses are recognised quickly.

Reaming

When the pilot hole is completed the bit, jetting sub and steering equipment is removed at the exit point. The pilot hole is then enlarged using conventional reaming; the reamer being pulled from exit towards entry. For larger diameter HDD's a number of incrementally larger reaming passes are required to open up the bore to final diameter.

During reaming the drilling fluid is pumped down through the drilling rods onto the cutting face of the reamer and then carries cuttings through the reamed hole to the exit pit. The fluid is transferred from the exit pit to the entry pit by either a HDPE returns line or by tractor and bowser. On this project a tractor and bowser will probably be used. At the entry point 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 rods 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 clear.

Once the reaming is completed to the entry point a cleaning run with a slightly smaller reamer is performed by pulling the reamer through the hole to ensure it is suitable for installing the pipeline.

Figure 31. Typical fly-cutter hole opener (left) and Barrel Reamer (right).

Pipeline or Duct Installation

The pipeline or duct will have been welded and placed along the stringing alignment prior to completion of the HDD reaming.

The pipeline or duct will be prepared for installation by attaching a pulling head (Figure 22) and if required it is ballasted by filling the pipeline / duct (or a duct within the pipeline) 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 / duct. 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 / duct is bolted to the swivel and pullback can begin.

Pullback proceeds by pulling back and removing a drilling rod then connecting onto the next drill rod and repeating. A typical installation rate for pullback is 100m per hour. During pullback the driller will monitor pulling forces to ensure the maximum allowable pulling force for the pipeline / duct is not exceeded.

During pullback the pipeline / duct will displace bentonite fluid from the borehole and at these locations it is expected to flow to the exit pit. There should either be ample storage prepared for the displaced fluid or sufficient bowsers / tankers to remove it from site without having to stop the installation process.

When the pulling assembly reaches the drilling rig it will be disconnected and removed. For PE ducts the pipeline should be secured to the drilling rig overnight so that the duct does not withdraw back into the borehole as elastic strain is recovered.

Figure 32. Drilling rod, swivel, pulling head and pipeline being pulled into the entry

APPENDIX E Conceptual Design Drawings

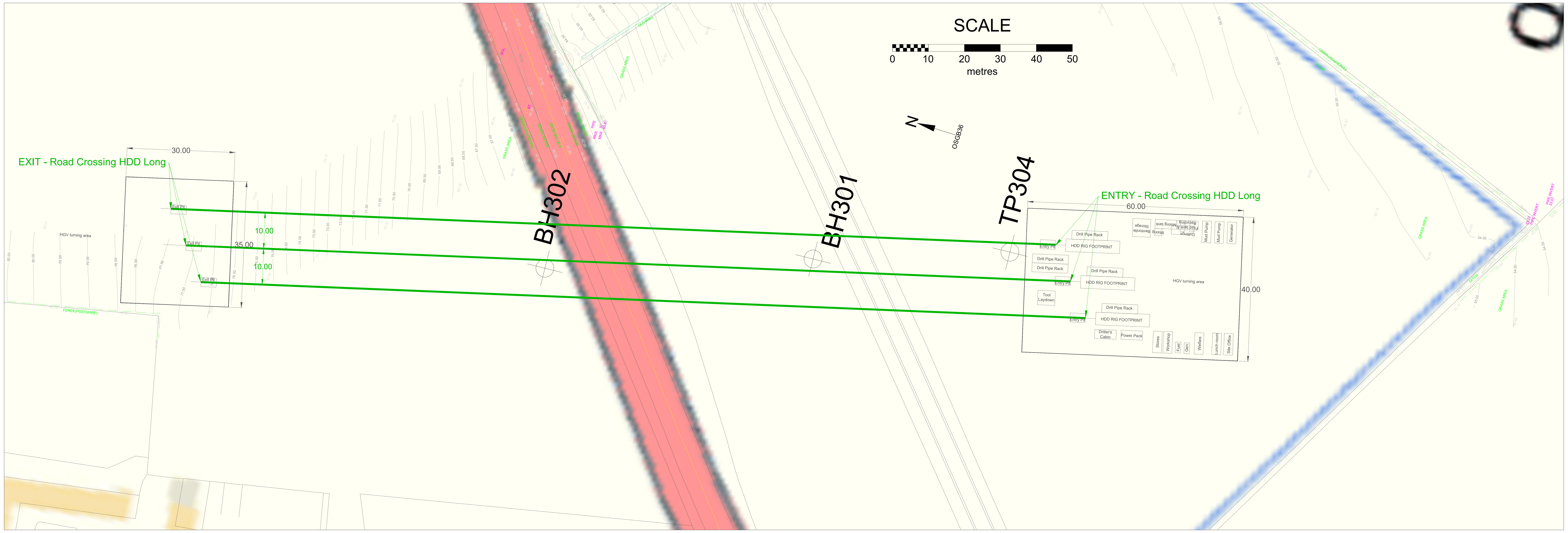
20160401RA-C/03 – Conceptual HDD Site Layout for Southern Design 5

20160401RA-C/07 – Conceptual HDD Design - South Alignment H

20160401RA-C/10 – Plan View comparing Conceptual HDD Designs

20160401RA-C/31 – Conceptual Maxi Rig HDD Design A90 & Railway Crossing

20160401RA-C/32 – Conceptual Mini Rig HDD Design A90 & Railway Crossing



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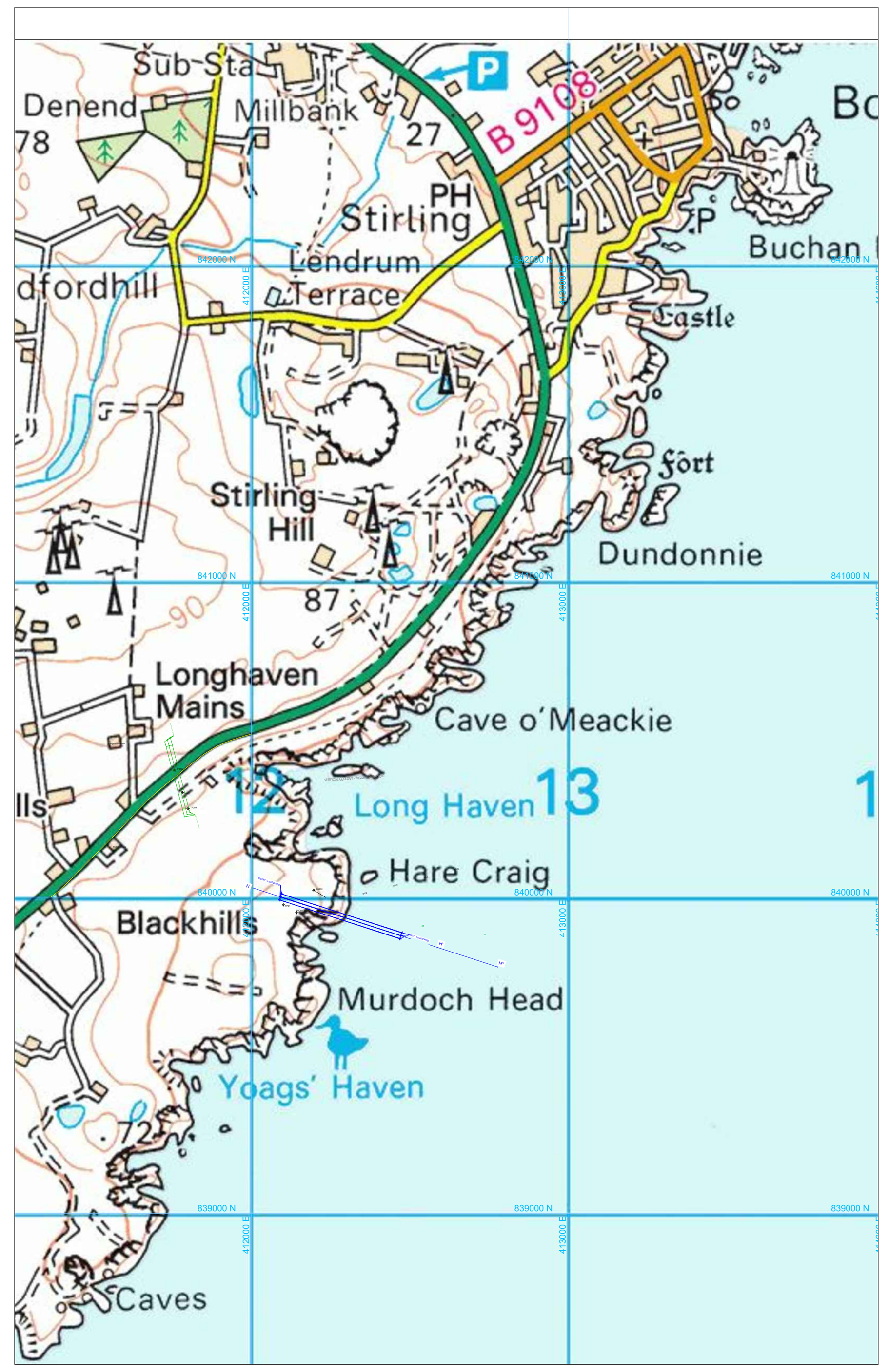

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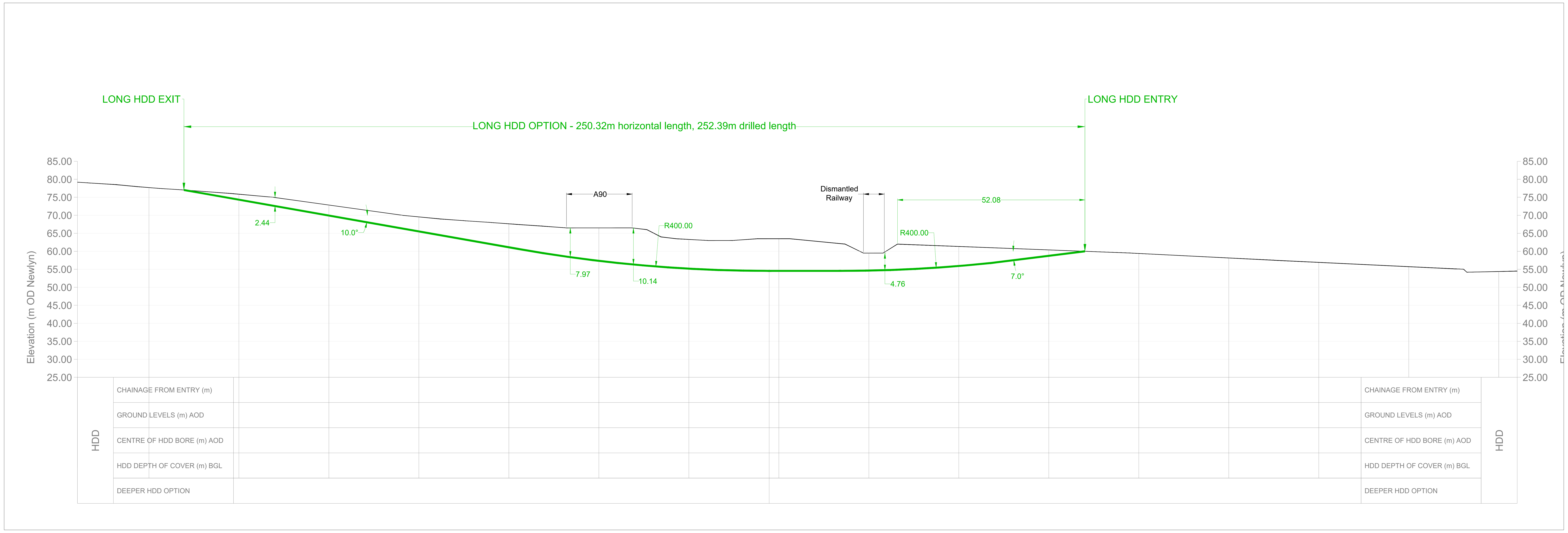
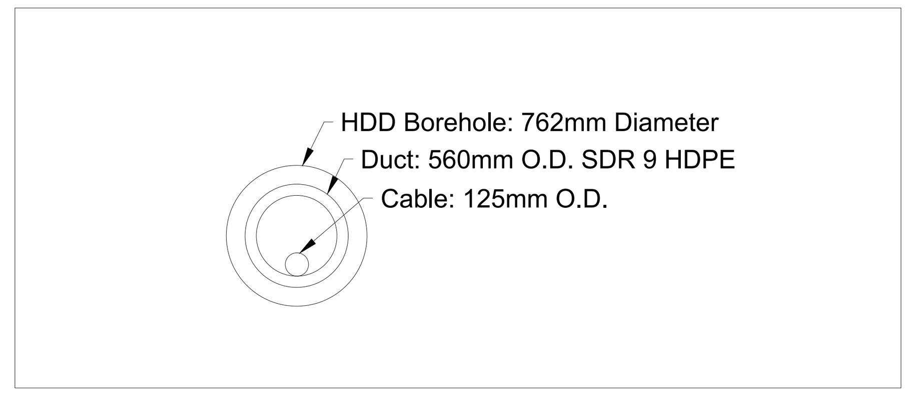


SECTION VIEW - SOUTHERN ALIGNMENT



DUCT DETAIL

NOTES

1. ALL DIMENSIONS, LEVELS AND CHAINAGES ARE IN METRES UNLESS OTHERWISE STATED. PROPOSED BOREHOLES ARE INDICATED BY YELLOW MARKERS.
2. LAND ELEVATIONS ARE ESTIMATED BASED ON OS MASTERMAP1:25,000 MAPPING AND TOPOGRAPHICAL SURVEY PROVIDED BY NORTHCONNECT
3. BATHYMETRY DEPTHS RELATES TO ADMIRALTY CHART DATUM. CHART DATUM IS -2.20 ODN MEASURED AT PETERHEAD.
4. GEOLOGY IS BASED ON HIGH LEVEL GEOLOGICAL MAPPING DURING THE RIGGALL & ASSOCIATES SITE VISIT. FURTHER GROUND INVESTIGATIONS WILL BE REQUIRED TO BETTER DETERMINE CONDITIONS AT SITE.

DO NOT SCALE

Rev	Date	Description	By
D	18/6/2018	Offshore survey boundary lines removed	TR
C	30/5/2018	Cosmetic changes for ITT	TR
B	11/03/2018	Removed North side Entry option	TR
A	06/02/2018	Draft for discussion	TR

Client: NORTHCONNECT

Scale	Drawn by	Date Drawn	Sheet Size
AS SHOWN	TR	16/10/2017	A1
Designed by	**Checked by**	**Approved by**	**Date approved**
TR			

Drawing Number: 20160401RA-C/31

Issue: A

Project Title: NORTHCONNECT HDD FEASIBILITY STUDY

Drawing Title: CONCEPTUAL LONG HDD DESIGN A90 & RAILWAY CROSSING

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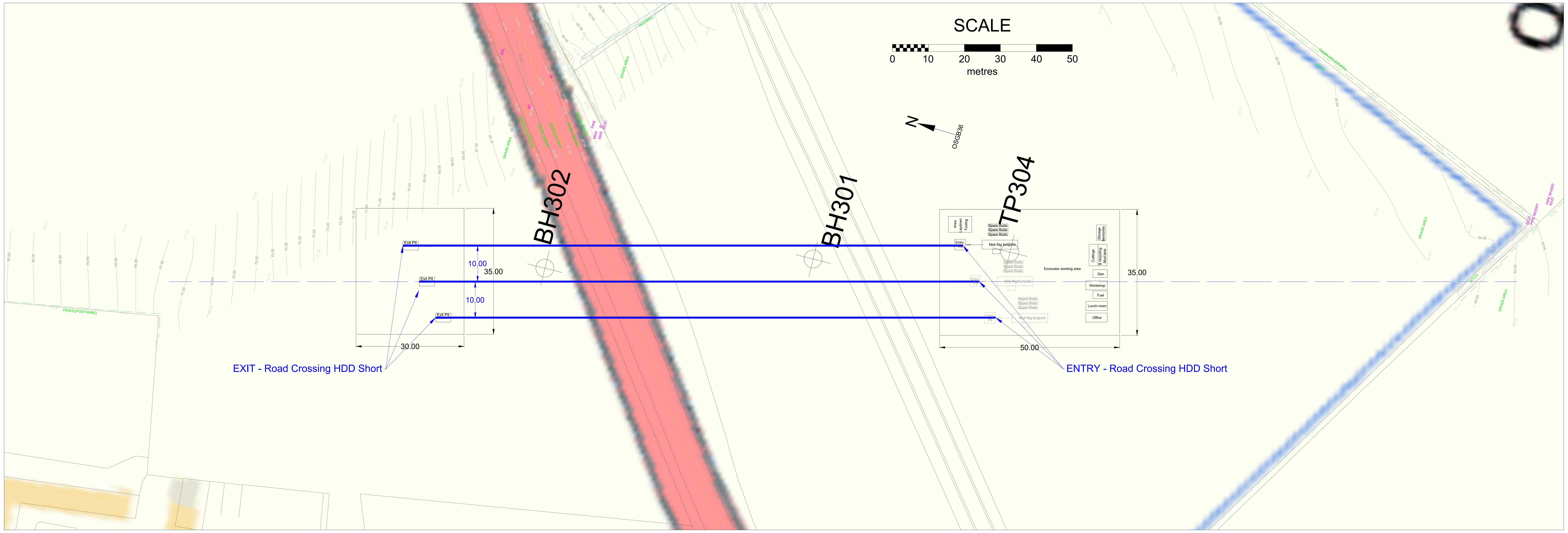
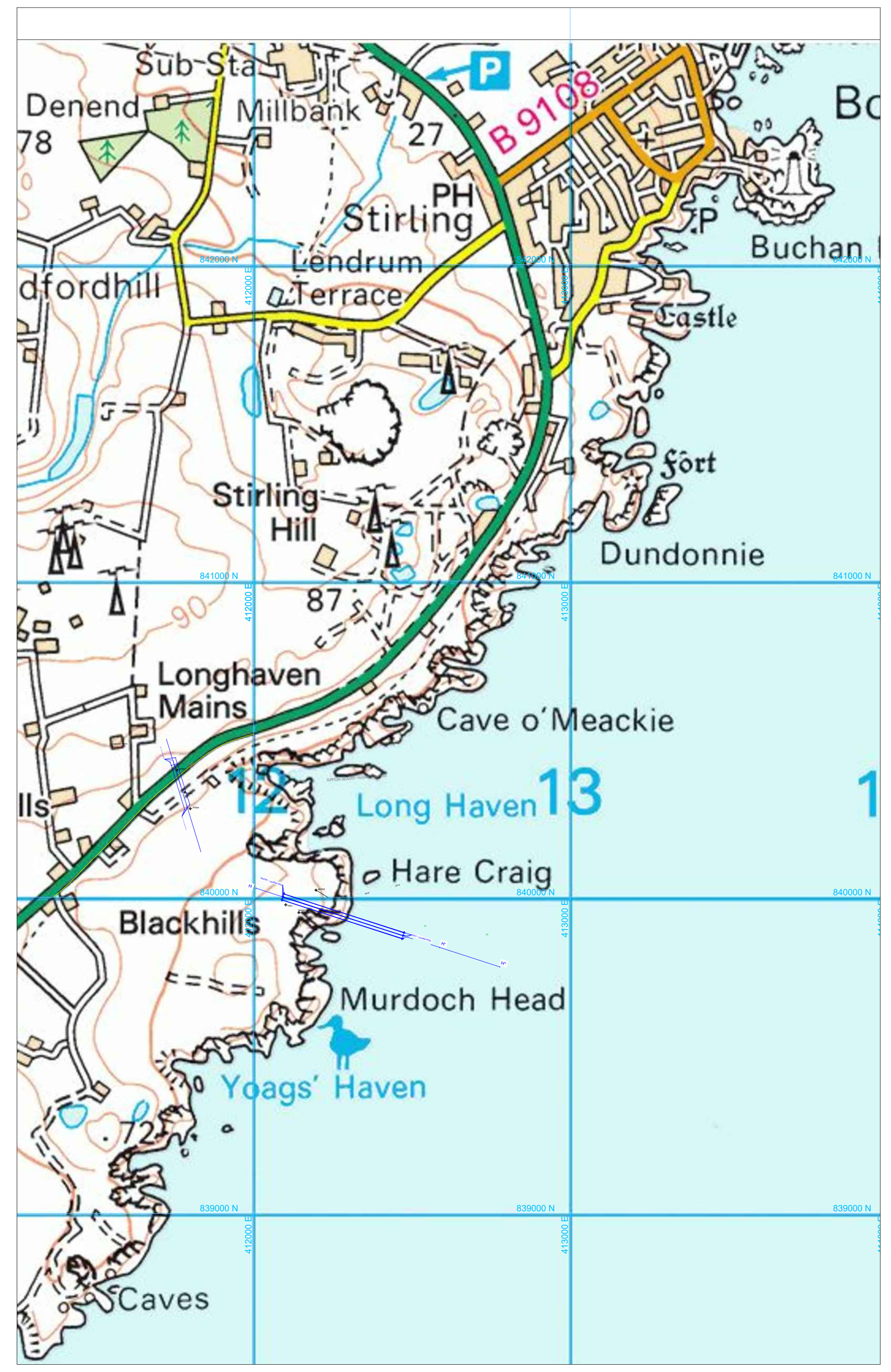


PLAN VIEW - SOUTHERN ALIGNMENT



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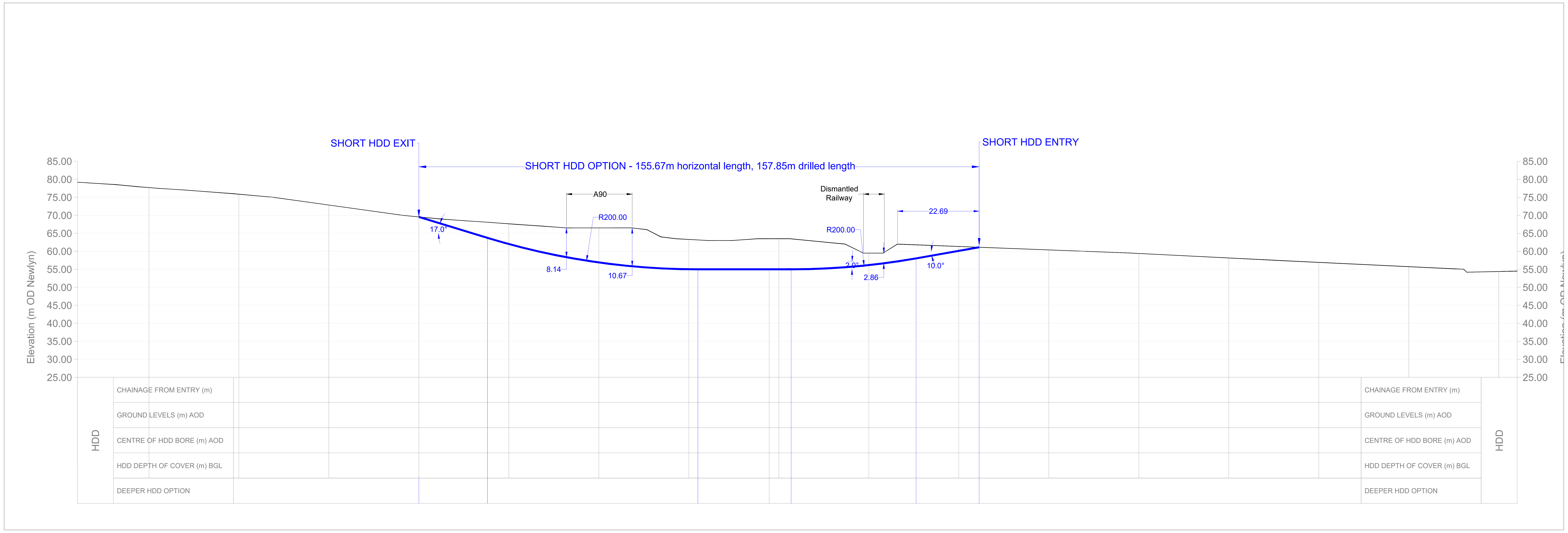
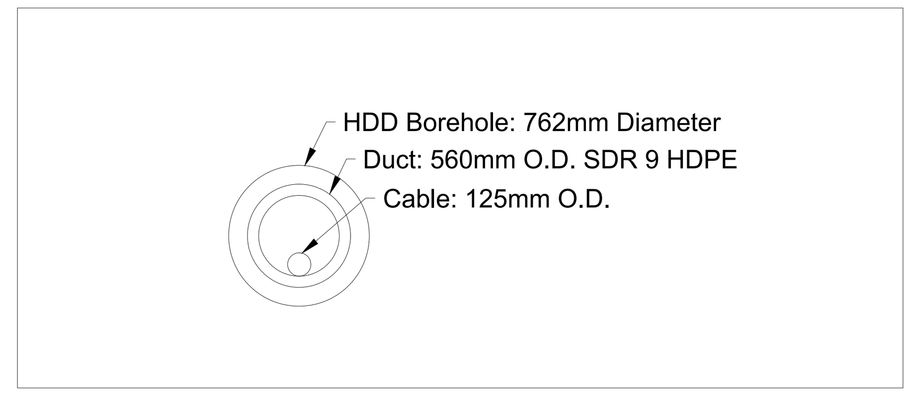


SECTION VIEW - SOUTHERN ALIGNMENT



DUCT DETAIL

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DO NOT SCALE

Rev	Date	Description	By
D	18/6/2018	Offshore survey boundary lines removed	TR
C	30/5/2018	Cosmetic changes for ITT	TR
B	11/03/2018	Removed North side Entry option	TR
A	06/02/2018	Draft for discussion	TR

Client: NORTHCONNECT

Scale	Drawn by	Date Drawn	Sheet Size
AS SHOWN	TR	16/10/2017	A1
Designed by	**Checked by**	**Approved by**	**Date approved**
TR			

Drawing Number: 20160401RA-C/32

Issue: A

Project Title: NORTHCONNECT HDD FEASIBILITY STUDY

Drawing Title: CONCEPTUAL SHORT HDD DESIGN A90 & RAILWAY CROSSING

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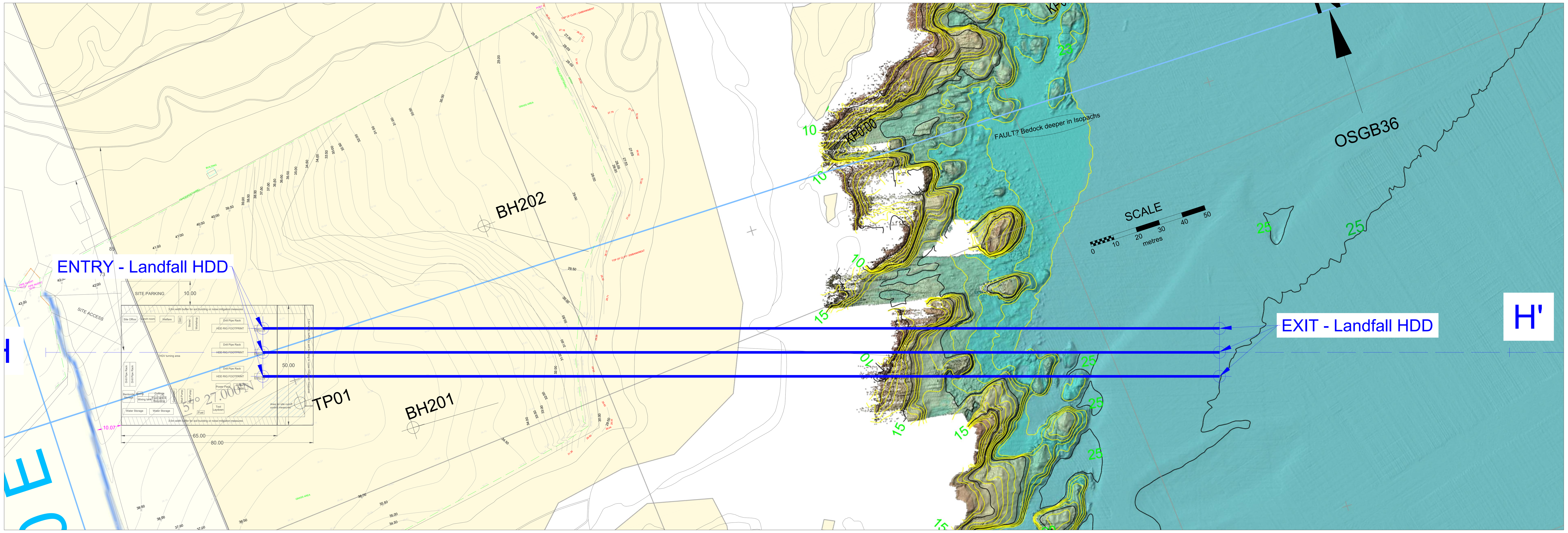

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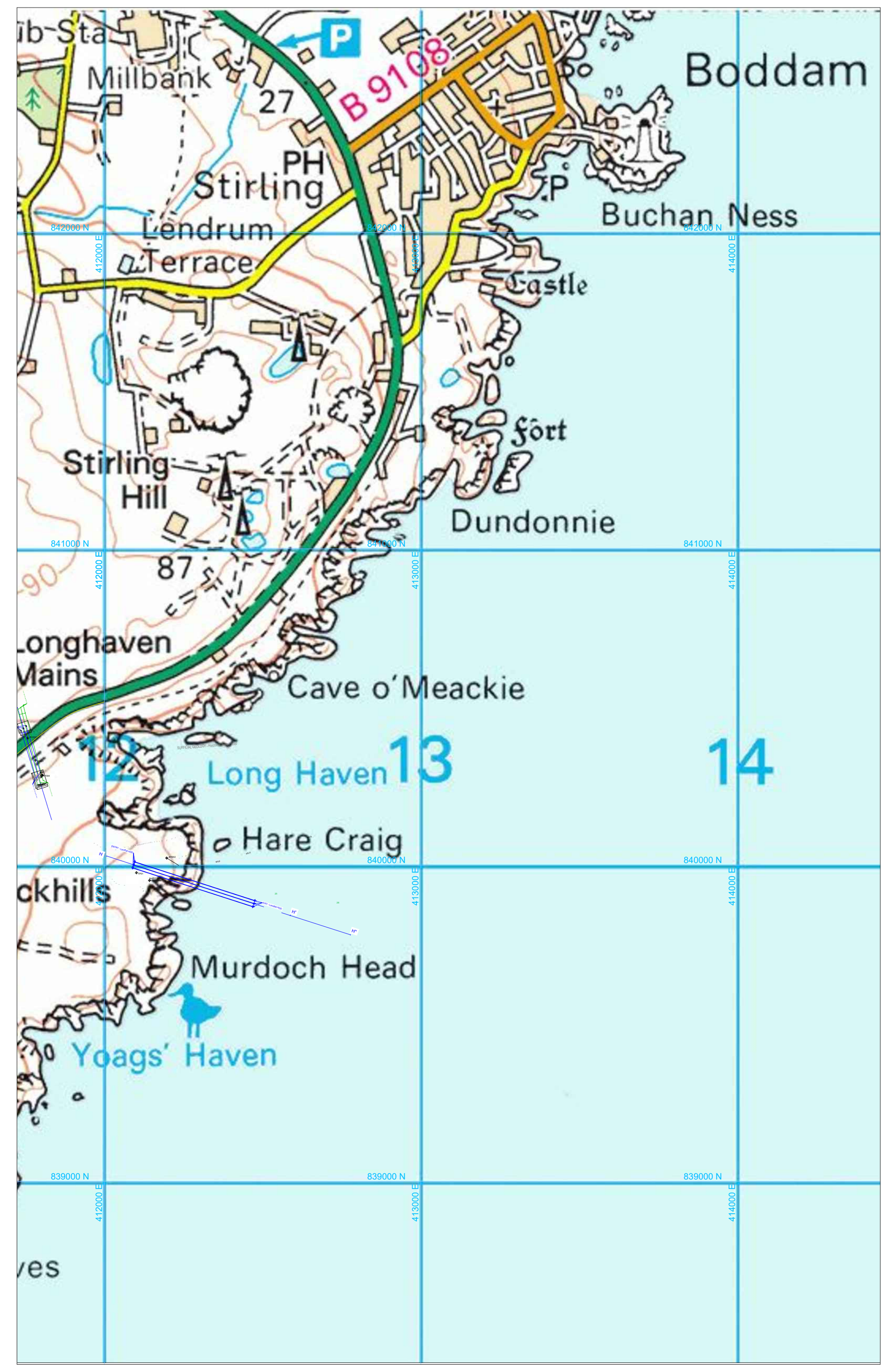

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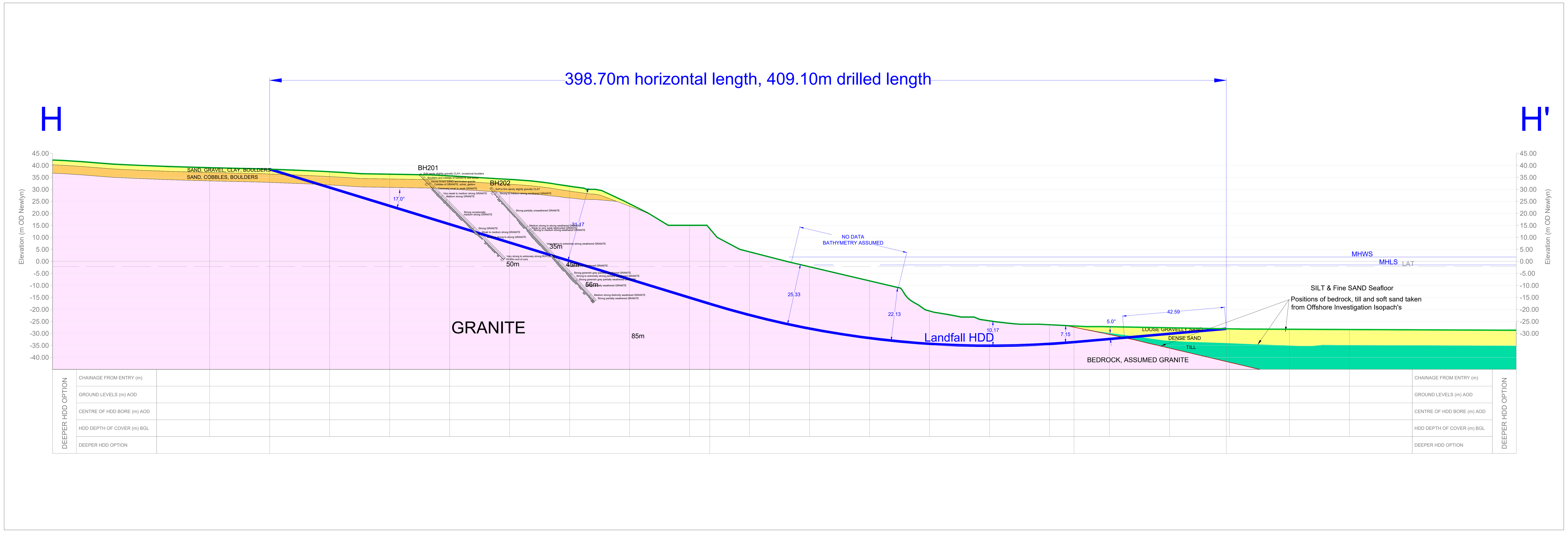

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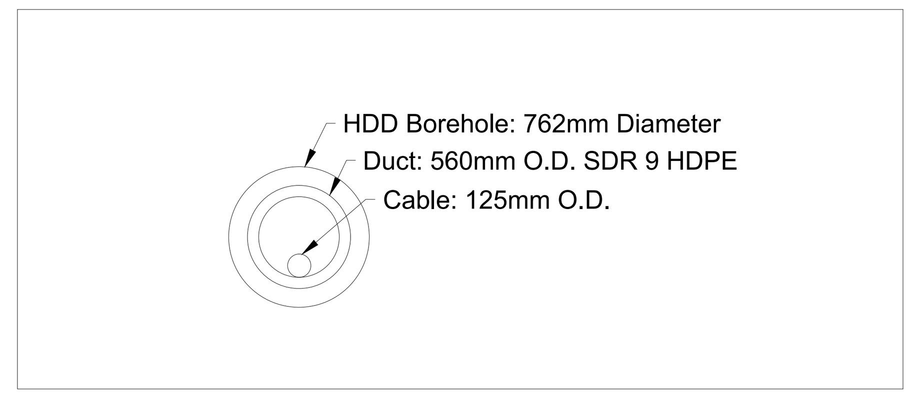

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DO NOT SCALE

Rev	Date	Description	By
E	18/6/2018	Offshore survey boundary lines removed	TR
D	30/5/2018	Cosmetic changes for ITT	TR
C	13/5/2018	Rev02 of Feasibility Report	TR
B	9/11/2017	Rev01 of Feasibility Report	TR
A	16/10/2017	Draft for discussion	TR

Client: NORTHCONNECT

Scale	Drawn by	Date Drawn	Sheet Size
AS SHOWN	TR	16/10/2017	A1
Designed by	**Checked by**	**Approved by**	**Date approved**
TR			

Drawing Number: 20160401RA-C/07

Issue: A

Project Title: NORTHCONNECT HDD FEASIBILITY STUDY

Drawing Title: CONCEPTUAL LANDFALL HDD DESIGN

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PLAN VIEW

NOTES

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DO NOT SCALE

Rev	Date	Description	By
F	18/6/2018	Offshore survey boundary lines removed	TR
E	30/5/2018	Cosmetic changes for ITT	TR
D	13/5/2018	Revision 2 of Feasibility Report	TR
C	7/02/2018	Revised layout to minimise noise	TR
B	9/11/2017	Updated for Southern Design 5	TR
A	20/05/2016	Draft for discussion	TR

Client: NORTHCONNECT			
Scale: AS SHOWN	Drawn by: TR	Date Drawn: 20/05/2016	Sheet Size: A1
Designed by: TR	Checked by:	Approved by:	Date approved:
Drawing Number: 20151001RA-C/03			Issue: A

Project Title

NORTHCONNECT
HDD FEASIBILITY STUDY

Drawing Title

CONCEPTUAL LANDFALL HDD SITE LAYOUT

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PLAN VIEW

NOTES

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DO NOT SCALE

Rev	Date	Description	By
D	18/06/2018	Offshore survey boundary lines removed	TR
C	30/05/2018	Cosmetic changes for ITT	TR
B	13/05/2018	For Rev02 HDD Feasibility Report	TR
A	7/02/2018	Draft for discussion	TR

Client: NORTHCONNECT

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AS SHOWN	TR	7/02/2018	A1
Designed by	**Checked by**	**Approved by**	**Date approved**
TR			

Drawing Number: 20151001RA-C/04

Issue: A

Project Title: NORTHCONNECT HDD FEASIBILITY STUDY

Drawing Title: DETAIL OF CONCEPTUAL HDD LANDFALL SITE LAYOUT

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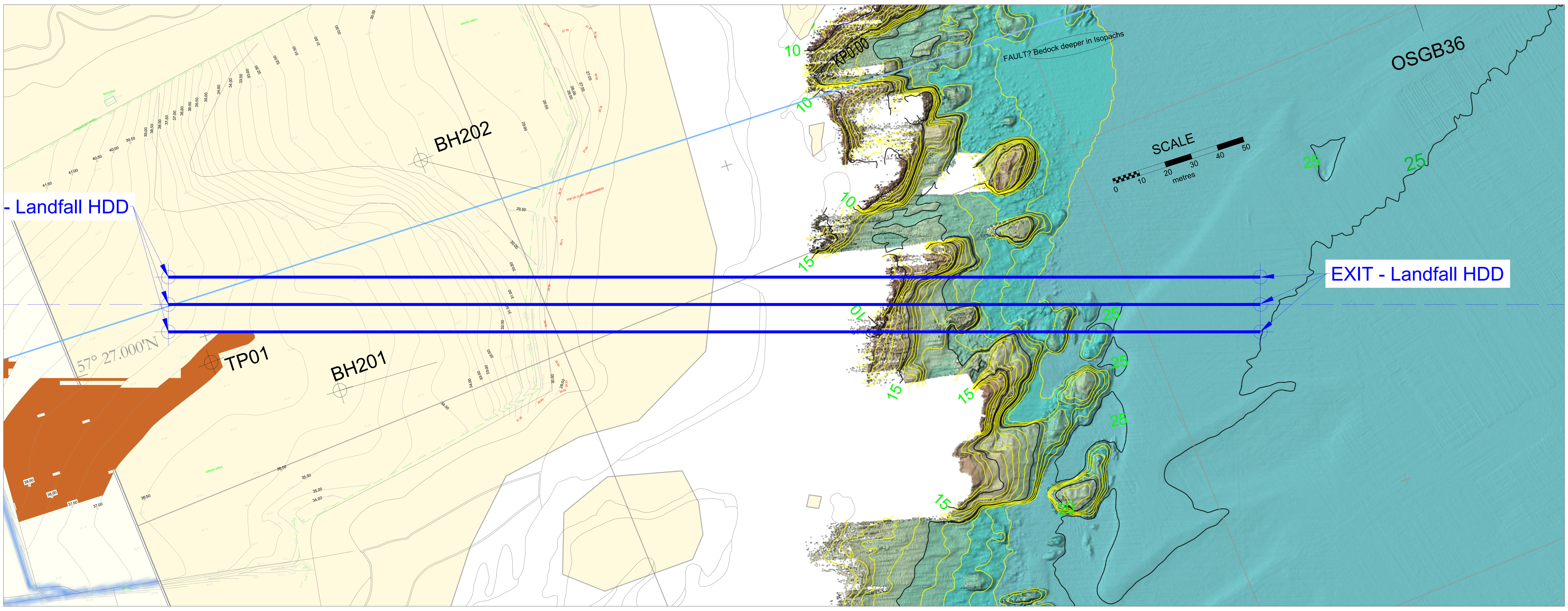
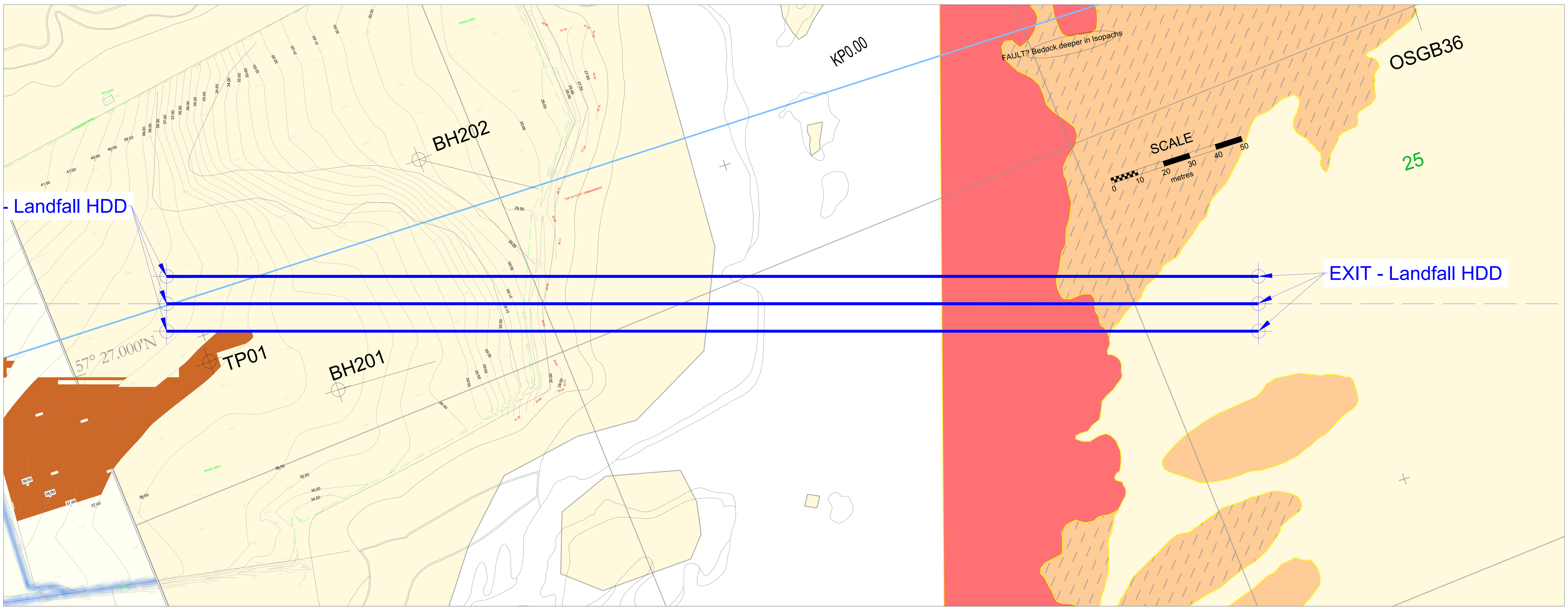


PLAN VIEW WITH BATHYMETRY



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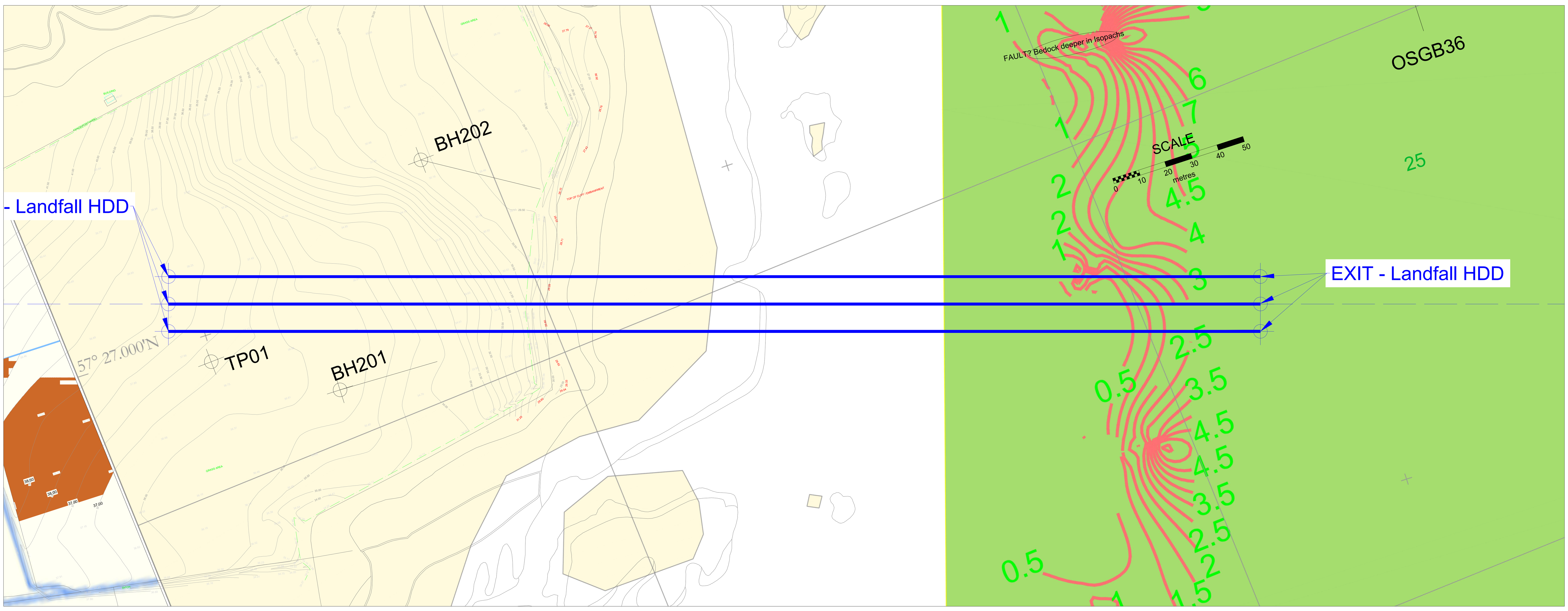

PLAN VIEW WITH ISOPACHS TO BEDROCK

NOTES

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D	30/5/2018	Cosmetic changes for ITT	TR
C	13/5/2018	Feasibility Report Rev02	TR
B	8/11/2017	Feasibility Report Rev01	TR
A	16/10/2017	Draft for discussion	TR

Client: NORTHCONNECT

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AS SHOWN	TR	16/10/2017	A1

Designed by	Checked by	Approved by	Date approved
TR			

Drawing Number: 20160401RA-C/10

Issue: A

Project Title

NORTHCONNECT
HDD FEASIBILITY STUDY

Drawing Title

PLAN VIEW COMPARING OFFSHORE SURVEY DATA FOR CONCEPTUAL HDD LANDFALL DESIGN

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