REPORT

Scour Assessment

Ardersier Port

Client:	Ardersier Port (Scotland) Ltd
Reference:	PC9062-HAS-XX-XX-RP-ME-0001
Status:	S5/P03
Date:	1 October 2026

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Appendices

Appendix A – Geotechnical Cross-Sections and Plan

1 Executive Summary

In response to NatureScot feedback on proposed changes to the layout of Ardersier Port, Ardersier Port (Scotland) Limited appointed Haskoning to undertake a propellor scour assessment of Whiteness Head – a dynamic sand spit on the Southern shore of Moray Firth, Scotland. NatureScot's concerns centre around the potential for propellor scour of the sand spit, which is a designated RAMSAR site. Ardersier Port (Scotland) Limited would like to understand if there is a reasonable risk of scour given the slow operational vessel speeds envisaged and their distance from the sand slopes.

Following data collection Haskoning have undertaken an assessment of both;

- the ground conditions to determine the erodibility of the soil and,
- the likely hydraulic forces generated by various vessel propulsion systems.

Combining these findings, Haskoning have concluded that there is a credible risk of scour (especially for loose surface deposits), due to the relatively soft ground and relatively large propellor forces from both; tugs assisting large vessels, and unassisted offshore wind installation vessels with large azipod thrusters.

Haskoning undertook sensitivity checks to investigate whether changes to the underlying assumptions (or introduction of operational controls) would make substantial changes to the conclusions of the assessment. Haskoning have investigated:

- The distance between the vessel propellers and Whiteness Head
- The percentage of power applied to the vessel thrusters
- The combined effect of changing the distance and the percentage of power applied
- The erosive properties of the sandy slopes

Haskoning found that a potential risk of scour (especially of loose surface deposits) remains, even if the underlying assumptions are altered or operational controls (such as limited applied engine power) are introduced.

Due to the uncertainties in erodibility it is however unclear how much erosion will occur (erosion cannot be predicted with currently available empirical or numerical methods), especially of the more erosion resistant underlayers of the spit. It is therefore concluded that operational controls to maintain a minimum distance from vessels to the spit slope alone would not adequately mitigate the risk of scour, therefore a buffer and monitoring approach is proposed.

2 Background

2.1 Project Site

2.1.1 Existing Layout

Ardersier Port is located on the south shore of the Moray Firth in North-east Scotland, approximately 18 km north-east of Inverness and opens directly into deep, sheltered water via a dredged access channel.



Figure 2-1: Satellite Image of Ardersier Port (courtesy of Bing Aerial mapping)

A buoyed entrance channel (~160 m wide) leads into the harbour, dredged to provide deep-water access for large vessels. The harbour includes a quay frontage (>650 m initially, with further ~1 km planned), forming the main berthing line for offshore wind vessels. Ongoing works include dredging, basin creation, and channel widening/deepening to accommodate heavy-lift and installation vessels.

A long linear quay wall (main berth + Ro/Ro berth) forms the operational waterfront. It is designed for high load capacity to support large offshore wind components.

Very large industrial “laydown” and marshalling areas (hundreds of acres) sit directly behind the quays. These are used for manufacture, assembly, storage and staging of offshore wind structures. The site is a repurposed brownfield fabrication yard, now reconfigured into an energy-transition hub. During operations, vessels arrive / depart from the quayside and navigate past Whiteness Head sand spit on the sheltered side (south-west of the spit).

2.1.2 Planned growth

Planned growth includes additional reclaimed land and extended development zones to the south/east, increasing total operational area beyond ~450 acres. Marine works will extend quay lines and enlarge the harbour footprint.



Figure 2-2 : Proposed Layout of Ardersier Port (courtesy of Scottish Offshore Wind Ports Alliance)

2.1.3 Whiteness Head

The sand spit at Whiteness Head forms part of a designated Ramsar site, meaning it is recognised as a Wetland of International Importance under the Convention on Wetlands (the Ramsar Convention), an international treaty adopted in Ramsar, Iran, in 1971. The Convention provides a global framework for the conservation and “wise use” of wetlands and seeks to maintain their ecological character while allowing sustainable human activities. Wetlands protected under the Convention include estuaries, mudflats, saltmarshes, lagoons, intertidal sandflats and other coastal habitats that support important ecological communities and migratory bird populations.

Ramsar sites are considered internationally important because they provide a range of environmental functions and ecosystem services. These include supporting nationally and internationally significant populations of birds, fish and other wildlife, maintaining biodiversity, storing carbon, improving water quality, and providing natural coastal protection. In Scotland, most Ramsar sites overlap with other protected area designations, such as Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and Sites of Special Scientific Interest (SSSIs), reflecting their high environmental value.

2.2 NatureScot Concerns

Ardersier Port (Scotland) Limited have provided Haskoning with a copy of a letter from NatureScot dated 16th January 2026 (ref: 25/04362/PIP) which amongst other items, sets out concerns related to propeller wash. The following extracts are of particular interest to the present study:

*"**Sandflats***

- *The sandflat habitat at the southeastern end of the inner harbour is potentially at risk of physical change due to post-dredging expansion/relaxation of the dredge slopes, which could be caused by prop-wash from vessels using that end of the harbour (likely to be semi-submersible barges and tugs).*
- *We do not currently have enough information to assess the impacts to the sandflat habitat and therefore advise on spit stability. However, this application is for planning permission, and we can expect further detail to be supplied in support of the Marine Licence application (due for submission to Marine Directorate in March 2026). Please refer the applicant to Annex C for the detail that we will require as part of their Marine Licence application.*

We note that the submarine rock armour proposed along the toe of dredged slopes in the inner harbour at the scoping stage for this development is not part of the current proposals."

and

"Annex C - Detail that we will require as part of their Marine Licence application in order to be able to assess impacts to intertidal sandflat habitats at the southeastern end of the inner harbour

i. A revision or addendum to the 2025 Stability Assessment, stipulating any minimum buffer width required to accommodate uncertainties regarding stability in natural conditions – a 'margin for safety' like that identified for the new spithead in the 2024 Stability Assessments.

ii. EITHER a vessel operations plan, enforceable through licencing, with further revision/addendum to the Stability Assessment confirming that this would rule out any risk of side-slope scour from 'prop wash'.

iii. OR further revision/addendum to the 2025 Stability Assessment, identifying the minimum buffer width (additional to any width identified in (i)) required to accommodate potential slope failure induced by 'prop wash'. This should take account of the largest / most powerful vessel that might be operated in the deepened inner harbour.

iv. A detailed design drawing(s) showing the dredge area, side slopes, up-to-date (post-reinstatement) position of MLWS, and SSSI boundary."

The environmental importance of the Whiteness Head sand spit is particularly linked to its role as an intertidal habitat. NatureScot has identified concerns that physical changes to the morphology of the spit, including erosion of sandflat habitats, could adversely affect the ecological features for

which the site is designated. NatureScot have raised specific concerns regarding the potential for propeller wash and vessel-generated hydrodynamic loading to cause erosion or instability of the dredged slopes, leading to undermining of the spit side slopes.

From a port operations perspective, Ramsar designation does not automatically prohibit navigation, dredging or port development. However, it places a greater obligation on operators and regulators to demonstrate that activities will not adversely affect the ecological character or integrity of the protected wetland. In Scotland, government policy requires Ramsar features to be treated in a similar manner to European protected sites when assessing land-use and marine developments. Consequently, plans or projects that may affect a Ramsar site are typically subject to detailed environmental assessment and may require demonstration that no significant adverse effects will occur.

Potential restrictions or controls on port operations may therefore include:

- Demonstration, through engineering assessment, that vessel propeller wash, thruster use and ship movements will not cause unacceptable erosion or sediment redistribution.
- Restrictions on vessel routes, manoeuvring practices, thruster usage or operating speeds where these could generate excessive bed shear stresses.
- Requirements for monitoring of shoreline position, bathymetry or habitat condition before and after development.
- Implementation of mitigation measures, such as defined navigation corridors, operational management plans, habitat management plans or physical scour protection where justified.
- Additional scrutiny during marine licensing, dredging consent and planning approval processes.

For the present study, the key issue is whether vessel-induced hydrodynamic forces associated with expected future port operations could cause erosion of the Ramsar-designated sand spit. Demonstrating that propeller-induced bed loads are insufficient to mobilise significant quantities of sediment, or that suitable mitigation (if required) is provided such that any resulting erosion would be negligible relative to natural coastal processes, is therefore an important component of satisfying NatureScot's concerns and supporting future port operations.

2.3 Existing Study

As part of a prior commission, Ardersier Port (Scotland) Limited appointed Fairhurst to undertake a stability assessment of Whiteness Head, considering the proposed dredged slopes. This report (APP2-FHT-SP-XX-RP-C-000001, Whiteness head Stability Assessment, March 2026) covers the geotechnical stability of the slopes and concludes that waves caused by vessel wash will not cause scour with reference to a further report on this subject (APP2-FHT-DD-CHA-RP-C-000002, Navigation Channel – Scour Assessment Report), An attempt was made to comment on propellor wash from vessels (Section A.2) (as repeated below), but the conclusions were insufficiently detailed and decisive to enable Ardersier Port (Scotland) Limited to progress discussions with NatureScot.

"The rotating propeller from vessels within the channel will generate a turbulent continuous stream of fast-moving water flow, which will result in significantly elevated bed flows over that of tidal currents and wind induced waves.

Owing to the effects of dispersion proportionate to the distance from the propeller axis to the bed level, the turbulent stream of water flow will intersect the bed level at a distance of four times this measurement, with high bed flow as calculated within the scour assessment report, extending up to a distance of ten times this distance. Beyond this range to the rear of the vessel, the bed velocities will rapidly diminish to that which would have negligible impact upon the channel bathymetric, hence would not present a significant risk to the ongoing stability of Whiteness Head.

The risk of propeller wash from vessel movements within the navigation channel impacting upon the stability of Whiteness Head is considered relatively low for vessels moving longitudinally within the channel, owing to the effects of dispersion due to the beams of vessels, as well as depth of water required to maintain sufficient under keel clearance to the bed of the channel. The risk of propeller wash impacting upon the spit from vessels manoeuvring to the berths will decrease with linear distance from the spit, owing to the effects of dispersion and as the position of influence from fast-moving water flow moves away from the spit, however ongoing monitoring will be required to ensure this does not impact the stability of Whiteness Head. It should be noted that owing to the quayside berthing alignment moving southwards, this dispersion is greater than that which could have occurred historically.

In conclusion it has been considered that owing to the sensitive characteristics of each vessel with reference to the calculated bed velocity, as well as the depth of the propeller axis from the vessel keel, it has been concluded that a watching brief will be implemented throughout Whiteness Head comprising regular bathymetric surveys to enable early identification of any potential scour holes resulting from propeller wash of vessels manoeuvring within the navigational channel. Undertaking a watching brief will enable the impacts of various vessel movements and operations within the

navigation channel to be analysed and reviewed on a case-by-case basis, to further refine and identify key locations which are affected by movements within the channel."

What would perhaps be more helpful, is a decisive statement as to whether there is negligible risk of scour, or an indication that scour protection is required to protect the dredged slopes.

2.4 Summarised Objective

The objective of this study is to provide independent aid to Ardersier Port (Scotland) Limited in satisfying NatureScot's concerns related to the potential for propellor induced scour and ship wave induced scour of Whiteness Spit.

3 Terrain

The bathymetry / topography is shown in Figure 3-1.

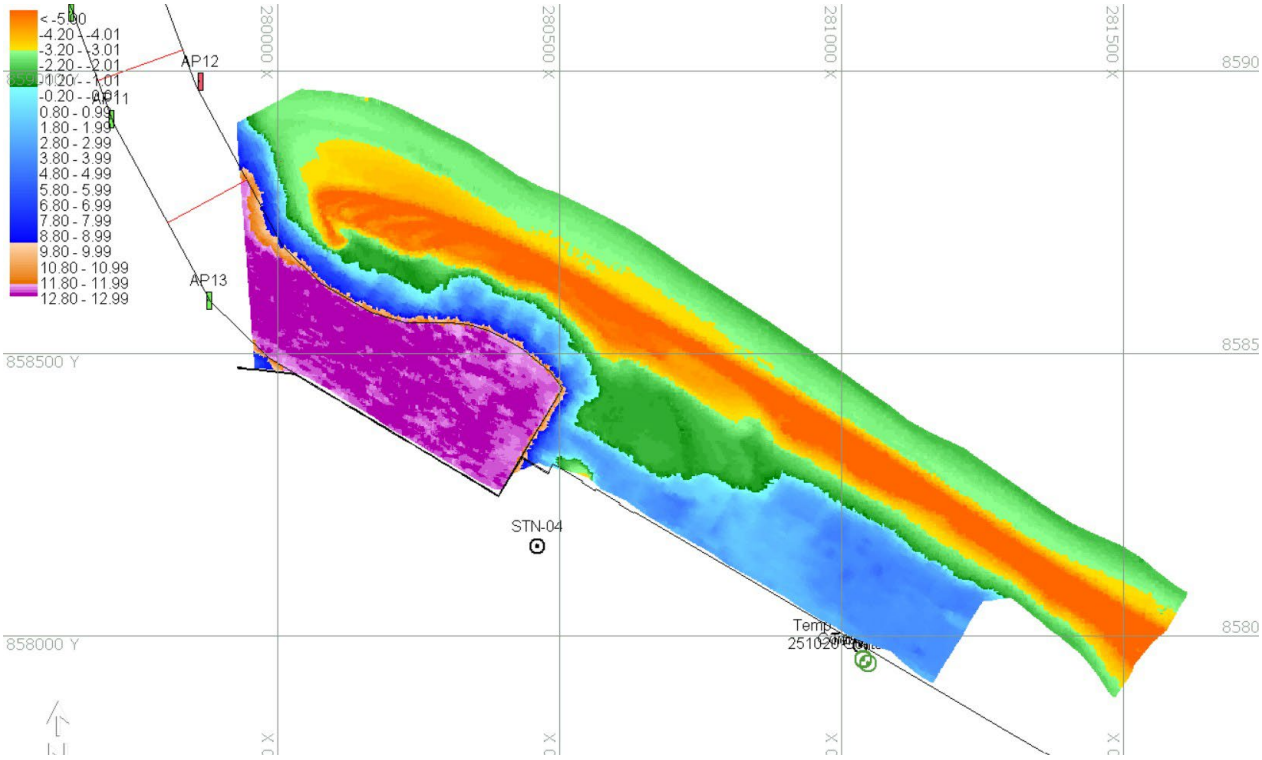


Figure 3-1: Terrain

Ardersier Port (Scotland) Limited provided this information as an .xyz file type, using the Ordnance Survey Great Britain 1936 co-ordinate system (OSGB36) system and references to Chart Datum (with depths being positive).

4 Metocean Conditions

4.1 Winds, Waves and Currents

For this study Haskoning has no access to information regarding wind, waves or tidal currents at the site. It is considered that erosion caused by metocean induced forces is unlikely to be act meaningfully in combination with propellor scour and therefore can be ignored in Haskoning's propellor scour assessment.

4.2 Water Levels

The following tidal levels were obtained by Haskoning from the UKHO Admiralty Tide Tables 2026 for the location of Whiteness Head:

Description	Abbreviation	Level relative to Chart Datum [+mCD]
Highest Astronomical Tide	HAT	+4.8
Mean High Water Springs	MHWS	+4.2
Mean High Water Neaps	MHWN	+3.3
Mean Sea Level	MSL	+2.5
Mean Low Water Neaps	MLWN	+1.7
Mean Low Water Springs	MLWS	+0.9
Lowest Astronomical Tide	LAT	+0.2

5 Ground Information

This section summarises the ground conditions at Ardersier Port and Whiteness Head as a basis for the scour assessment. The published geology is reviewed from British Geological Survey (BGS) mapping and memoir information (Fletcher, et al., 1996; British Geological Survey, n.d.) and compared against the recent project ground investigations, from which the geological units and erodibility characteristics adopted for the assessment are derived.

5.1 Superficial Geology

Ardersier Port lies on the low-lying southern shore of the Inner Moray Firth, and Whiteness Head is a coastal barrier and shingle spit developed through longshore transport. BGS mapping identifies Holocene beach, storm-beach, tidal-flat and marine deposits around the Ardersier coast, principally sand and gravel with finer sand, silt and clay in sheltered tidal and estuarine settings (Fletcher, et al., 1996; British Geological Survey, n.d.). The sequence varies over short distances: Late Devensian glaciomarine silts and gravels are locally overlain or bordered by raised marine, tidal-flat, beach and blown-sand deposits, and reclamation has added a local cover of artificial ground.

The superficial geological units expected beneath the site are summarised in Table 5-1 and the mapped superficial geology is shown in Figure 5-5-1. The units proven by the project ground investigations are described in Section 5.5.

Table 5-1: Expected superficial geological units from published mapping

Geological unit	Typical published description	Expected distribution / comment
Artificial ground / reclaimed ground	Heterogeneous placed or reworked soils, potentially including dredged material and construction fill.	Likely within the operational and reclaimed port footprint. Its extent and composition are not resolved by regional geological mapping.
Blown sand	Generally fine- to medium-grained windblown sand, commonly loose and locally forming dunes or low coastal ridges.	Mapped on parts of Whiteness Head and the coastal barrier.
Beach deposits (Holocene)	Sand and gravel or shingle, locally with cobbles and shell material, deposited along active or recent shorelines.	Mapped along the outer shore and around parts of Whiteness Head.
Intertidal deposits, undifferentiated (Holocene)	Variable sand, silt and clay deposited within the present tidal zone; locally organic or shelly.	Mapped around the harbour margins and tidal flats.
Raised marine deposits (Holocene)	Predominantly sand and gravel representing former beaches and shallow-	Mapped across parts of the port hinterland and coastal barrier.

Geological unit	Typical published description	Expected distribution / comment
	marine deposits above the present shoreline.	
Raised tidal-flat deposits of Holocene age	Silt and clay with variable fine sand, representing former low-energy tidal-flat environments.	Mapped landward of the present tidal margins near the port.
Ardersier Silts Formation (Late Devensian)	Silt and very fine-grained sand with local clay or diamictic mud, deposited in a glaciomarine setting.	Expected regionally beneath the younger Holocene coastal sequence. Not positively identified in the recent project ground investigations (Section 5.5).
Alturlie Gravels Formation (Late Devensian)	Sand and gravel, commonly coarsening upwards, associated with glaciomarine delta or fan deposition.	Present in the wider district and may occur beneath or adjacent to younger deposits. Not positively identified in the recent project ground investigations (Section 5.5).

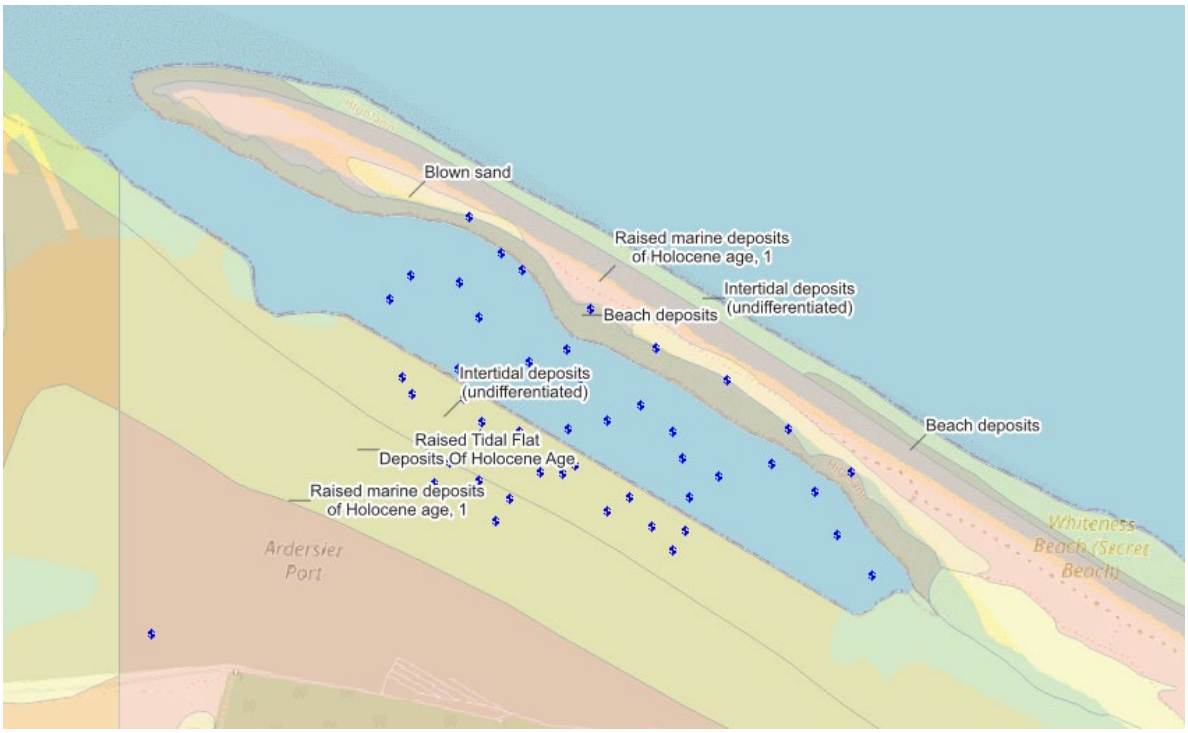


Figure 5-1: Published superficial geology around Ardersier Port and Whiteness Head

The recent ground investigations prove sand-dominated Holocene marine deposits to about -54mCD and did not positively identify the older Ardersier Silts Formation or Alturlie Gravels Formation within the depths investigated (Section 5.5).

5.2 Solid Geology

The BGS memoir places the site within the Devonian Old Red Sandstone district at the south-western margin of the Orcadian Basin, with the Hillhead Sandstone and Nairn Sandstone formations mapped in the Ardersier-Cawdor area (Fletcher, et al., 1996). The Nairn Sandstone Formation is exposed on a wave-cut platform east of Whiteness Head, but bedrock beneath the port is concealed by thick superficial deposits.

Bedrock was not encountered in the deepest project boreholes (60.45 m below ground level; Section 5.4) and is unlikely to influence dredging or seabed response, although its depth remains relevant to any deep foundations.

5.3 Hydrogeology

Groundwater in the sand- and gravel-dominated superficial deposits is expected to be hydraulically connected to the harbour and tidally influenced. These deposits are of moderate to high permeability, and excavations and dredged slopes may be prone to rapid seepage, running sand and local piping; the existing stability assessment identifies piping as a potential mechanism in the newly placed reinstatement material (Fairhurst, 2026). Groundwater vulnerability and

geoenvironmental matters are outside the scope of this assessment and are addressed in the geotechnical desk study.

5.4 Available GI Data

Four factual ground investigation reports by Solmek cover the Phase 2 works and are the primary sources for this review (Table 5-2). Together they provide 232 exploratory locations: 52 boreholes, 40 piezocone penetration tests (CPTu) and 140 super heavy dynamic probes (DPSH). Descriptive logs suitable for stratigraphic interpretation are available for 47 boreholes; the remaining locations provide penetration resistance, coordinates and depths only.

Earlier investigations, at the quay in 2022-2023 (Solmek contract S221111) and on the spit in 2023 (boreholes BH-SP05 to BH-SP09), are reported in the Arup and Fairhurst stability assessments (Fairhurst, 2026; Arup, 2024), these have not been received or included.

Table 5-2: Summary of available ground investigations

Package	Report ref (date)	Boreholes	Hole IDs	Depth range	Other in-situ testing	Notes
Phase 2 Spit	S250403 (March 2026) (Solmek, 2026)	8 cable percussive	BH-101, BH-102, CP-101–CP-104, CP-201, CP-202	21.45–30.0 m bgl	—	Drilled on Whiteness Head, Sept–Oct 2025
Phase 2 Marine and Landside	S250403 (March 2026) (Solmek, 2026)	19 sonic (marine) + 5 sonic (landside)	BH-106–BH-119, BH-201–BH-207 (marine); BH-301–BH-305 (landside)	16.91–34.75 m (final depths)	—	Marine holes drilled from overwater plant across inner harbour and chan nel; moonpool/water column interval s of 1.2–8.5 m recorded as voids. Landside l ogs not included and ground levels n ot stated — request from Solmek
Phase 2 Quay Wall	S240936 (July 2025) (Solmek, 2025)	15 sonic	P2-BH01–P2-BH04, P2-BHAW01–P2-BHAW05, P2-BHFW01–P2-BHFW05, P2-BHLA01	6.0–60.45 m	30 CPTu, 140 DPSH	Across quay wall and anchor wall ali gnments
Launch Pocket	S250401 (August 2025) (Solmek, 2025)	5 sonic	P2-BHAW06, P2-BHAW07, P2-BHFW06–P2-BHFW08	45.45–60.45 m	10 CPTu	—

5.5 Stratigraphy

The logged descriptions are grouped into eight geological units: Made Ground (MG), reinstated dredged sand (REI), blown sand and beach deposits (CSD), a surficial organic seabed veneer (TFD-O), tidal flat deposits (TFD-C coarse, TFD-F fine) and Holocene marine deposits, undifferentiated (HMD-C coarse, HMD-F fine). Unit boundaries were assigned from the logged descriptions, colours and inclusions and were reviewed against normalised penetration resistance ((N1)60) and the laboratory data. The supporting digitised logs and SPT normalisation analysis are presented in the appendices.

The geological units adopted for the ground model are summarised in Table 5-3. Elevations are quoted in mCD.

Table 5-3: Geological units adopted for the ground model

Unit	Origin	Typical description	Proven elevation (mCD)	Thickness (m)	(N1)60 band means
MG	Made Ground / artificial ground	Sand with variable gravel, cobbles and anthropogenic fragments; includes reworked and hydraulically placed sand	+7.2 to +1.0	typically 2-4, up to 5.2	20-90 (shallow tests)
REI	Made Ground - reinstated dredged sand (placed February 2025)	Loose to medium dense light brown to beige SAND, locally gravelly; placed dredge arisings	+3.8 to +1.2	2.3-2.6	14-20 (two tests)
CSD	Blown sand and beach / storm-beach deposits (Holocene)	Light brown to brown fine to medium SAND, locally gravelly; rounded gravel, shell fragments	+5.2 to -10.1	10-14.5 at the spit crest; 1-2 at the quay	15-113
TFD-O	Tidal flat / seabed surface deposits, organic (Holocene, active)	Loose black organic-rich SILT to very silty SAND with frequent organic and timber insertions	+1.4 to -7.8	typically 1, up to 3.7	7-20 (four tests)
TFD-C	Tidal flat / intertidal deposits (Holocene)	Dark grey silty SAND with organic lenses, seeds, timber fragments and shells	+4.7 to -19.9	typically 2.5, up to 13.6	18-48
TFD-F	Tidal flat / intertidal deposits (Holocene)	Dark grey to black sandy, clayey SILT; organic odour	-3.4 to -9.2	typically 0.6, up to 1.4	23-33
HMD-C	Marine deposits, undifferentiated (Holocene)	Grey to dark greyish brown silty SAND, locally gravelly or very silty; shell fragments	-3.2 to -54.2 (base unproven)	typically 5, up to 27	24-58, declining with depth
HMD-F	Marine deposits, undifferentiated (Holocene)	Very soft to firm clayey, sandy SILT bands	-13.1 to -37.0	typically 4, up to 10.7	5-13

Made Ground (MG) is recorded in 20 boreholes, all in the quay wall and launch pocket areas, as sand with gravel, cobbles and anthropogenic fragments to about 5 m depth.

Reinstated dredged sand (REI) is proved in the upper 2.6 m at BH-101 and BH-102 on the landward face of Whiteness Head; both holes were positioned at the estimated mean high water springs line to check the material placed in February 2025. Loose to medium dense clean brown sand (SPT N of 6 to 9) rests on darker organic-lensed tidal flat sand, and the Fairhurst addendum reports the replaced sands performing akin to the natural stratification (Fairhurst, 2026).

Blown sand and beach deposits (CSD) form the body of the spit. In the six crest holes (CP-101 to CP-104, CP-201 and CP-202) the unit runs from crest level at +3.7 to +4.6 mCD down to a consistent colour change to grey silty sand at -6.4 to -10.1 mCD, giving 10 m to 14.5 m of clean brown to beige sand, locally gravelly with rounded clasts and rare shell fragments. The colour change is interpreted as the tidal flat or marine surface over which the spit prograded, and the CSD base is mapped at the first grey or silty horizon in each hole. Thin occurrences are also recorded at the quay and launch pocket.

Surficial organic seabed deposits (TFD-O) form a veneer at the seabed in the overwater boreholes across the inner harbour and channel, typically about 1 m thick and up to 3.7 m locally. The few penetration tests within it give (N1)60 of 7 to 20, the loosest natural material recorded on the site. This is the material first exposed to vessel-induced flows and is the unit most relevant to the assessment of physical change to the sandflat.

Tidal flat deposits (TFD-C and TFD-F) underlie the surficial veneer beneath the harbour, channel and spit flanks between about +4.7 mCD and -19.9 mCD. The unit is dominated by dark grey silty sand (TFD-C) with organic lenses, seeds, timber fragments and shells, and contains thin subordinate silt and clay bands (TFD-F), typically less than 1.5 m thick, between -3.4 mCD and -9.2 mCD. At BH-112 two thick strata logged as sandy SILT are included in TFD-C on the laboratory evidence (non-plastic, sand-grading particle size distributions).

Holocene marine deposits (HMD-C) are the principal unit at depth across the whole site and continue to the base of the deepest boreholes at -54.2 mCD without reaching their base. They comprise grey silty sand, locally gravelly or very silty, with shell fragments. This is the main unit exposed at the proposed dredged faces and below the harbour seabed, together with TFD-C in the shallower cuts; the undredged seabed around the works remains blanketed by the TFD-O veneer.

Fine-grained marine bands (HMD-F) occur within the deeper sands in 19 boreholes, mainly beneath the quay wall and launch pocket, between -13.1 mCD and -37.0 mCD. They are very soft to firm clayey, sandy silts, typically 2 m to 8 m thick, with normalised (N1)60 of 5 to 13. The earlier CPT-based interpretation dismissed a clayey silt signature at similar depths as spurious (Arup,

2024); the boreholes confirm these bands are real. They lie well below the proposed dredge levels but are relevant to settlement, drainage and any deep foundations.

Table 5-4 relates the units to those used in the earlier stability assessments. The earlier studies adopted elevation-banded engineering units, so the correspondence is approximate and the boundaries do not coincide exactly.

Table 5-4: Correlation with the units used in the Arup and Fairhurst stability assessments

This study	Arup (2024) (Arup, 2024)	Fairhurst (2026) (Fairhurst, 2026)
MG	Hydraulic fill and made ground (quay area)	Not modelled
CSD	Gravelly sands (above -5 to -7 mCD)	Dense Sandy Gravel (+6.4 to +1.5 mCD)
TFD-O	Not modelled separately	Not modelled separately
TFD-C / TFD-F	Transitional sands (-5/-7 to -12.5 mCD)	Medium-Dense Sand, silty and gravelly (+1.5 to -7.8 mCD)
HMD-C	Silty sands / older Holocene marine deposits (below -12.5 mCD)	Medium-Dense Sand and Dense Sand (-7.8 to -30.3 mCD)
HMD-F	Not modelled; a deep clayey silt CPT signature was dismissed as spurious	Not modelled
REI (proved at BH-101 and BH-102; wider extent from surveys pending)	Not applicable (pre-dates placement)	Fine-Medium Grain Sand (Reinstatement); Addendum 1 reports it performing as the natural sands

5.6 Erodibility

5.6.1 Present state of knowledge

It is assumed that erosion characteristics of soils apply as per those outlined in the academic paper “Erosion Charts for Selected Geomaterials” by Briaud, Govindasamy and Shafii, published in the October 2017 issue of the Journal of Geotechnical and Geoenvironmental Engineering (Briaud, Govindasamy, & Shafii, 2017), and similar international guidance. Key extracts are reproduced in Figure 5-2 and Figure 5-3 below.

Table 1. Erosion Categories and Their Threshold Values

Erosion category	Description	Critical shear stress, τ_c (Pa)	Critical velocity, v_c (m/s)
I	Very-high-erodibility geomaterials	0.1	0.1
II	High-erodibility geomaterials	0.2	0.2
III	Medium-erodibility geomaterials	1.3	0.5
IV	Low-erodibility geomaterials	9.3	1.35
V	Very-low-erodibility geomaterials	62.0	3.5
VI	Nonerosive materials	500	10

Figure 5-2: Erosion categories and threshold values (reproduced from Briaud, Govindasamy, & Shafii, 2017)

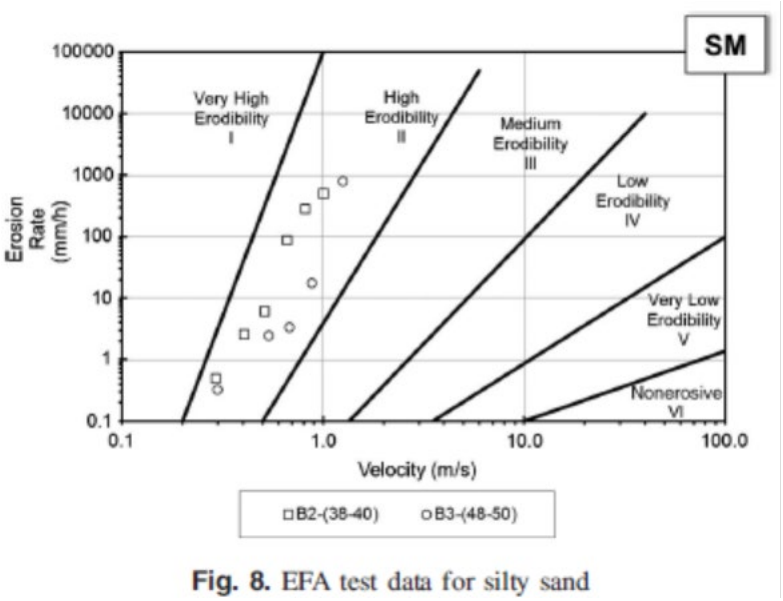


Fig. 8. EFA test data for silty sand

Figure 5-3: Erosion function apparatus (EFA) test data for silty sand (SM) (reproduced from Briaud, Govindasamy, & Shafii, 2017)

The soils that will be exposed at the dredged faces and on the adjacent seabed are the Holocene tidal flat and marine deposits (units TFD-C and HMD-C, grey silty fine SANDs), locally blanketed by the organic seabed veneer (TFD-O), with the blown sand and beach deposits (CSD) forming the upper part of the spit (Section 5.5). These soils are characteristically silty fine sands, which aligns with high erodibility geomaterials. From an interpretation of the plots within this paper, the critical velocity to instigate erosion is considered to be 0.3m/s.

The particle size distribution (PSD) test results from the recent ground investigations (187 tests in total) have been collated and assigned to the geological units described in Section 5.5 and to elevation zones defined relative to the proposed dredged slope. The results for the zones relevant to this assessment (118 tests) are summarised in Table 5-5. Within and below the dredged slope profile (below 0mCD) the D50 is typically 0.09mm to 0.20mm (fine sand), rising to approximately

0.2mm to 0.27mm in the crest / intertidal zone (locally coarser within the Made Ground), with median fines contents typically between 2% and 15% (non-plastic).

Table 5-5: Summary of D50 and fines content by elevation zone and geological unit (data from the Solmek factual reports)

Zone	Elevation (mCD)	Unit	No. of tests	D50 range (mm)	D50 median (mm)	Median fines (%)
Crest / intertidal	0.0 to +4.5	REI	4	0.185 – 0.198	0.193	6.5
		MG	6	0.202 – 0.378	0.223	5.5
		CSD	13	0.187 – 0.250	0.216	2.0
		TFD-C	8	0.198 – 0.267	0.226	4.0
		HMD-C	4	0.228 – 0.269	0.231	6.5
Upper slope	-5.0 to 0.0	CSD	6	0.164 – 0.199	0.178	3.5
		TFD-C	9	0.102 – 0.251	0.185	5.0
		TFD-O	2	0.164 – 0.170	0.167	9.8
		HMD-C	5	0.171 – 0.219	0.184	2.0
Lower slope	-10.0 to -5.0	CSD	4	0.147 – 0.164	0.158	5.0
		TFD-C	18	0.105 – 0.198	0.159	8.0
		TFD-F	1	0.162	0.162	8.0
		TFD-O	2	0.104 – 0.165	0.135	14.0
		HMD-C	11	0.092 – 0.193	0.154	15.0
Toe / base of slope	-12.9 to -10.0	TFD-C	6	0.042 – 0.167	0.100	14.3
		HMD-C	7	0.093 – 0.180	0.112	11.1
Below toe	-16.0 to -12.9	TFD-C	3	0.089 – 0.176	0.169	6.0
		HMD-C	9	0.082 – 0.186	0.123	14.0

As summarised in Table 5-5, the D50 of samples within the dredged slope profile typically ranges from 0.10 to 0.2mm, reducing to approximately 0.1mm towards the toe of the slope. Following Soulsby (1997), the critical velocity for the onset of motion in sands with a D_{50} size 0.10mm - 0.2mm on a flat bed have a depth averaged critical velocity of approximately 0.4m/s. However, accounting for the bed slope effects (Soulsby 1997) the critical velocity for a 0.1mm sand reduces to 0.35 m/s (0.36m/s for d50=0.2mm).

It is noted that the sands within and beneath the dredged slope profile are typically in a medium dense to dense state (Table 5-3). For non-cohesive soils, however, the threshold at which erosion begins is governed by the size and submerged weight of the individual grains (Shields-type criteria; Soulsby, 1997), rather than by the relative density of the soil mass. Erosion of sand takes place

grain-by-grain, and a medium dense fine sand therefore begins to erode at essentially the same critical velocity as a loose fine sand of the same grading; density and silt content principally influence the rate and bulk volume of erosion rather than its onset. Similarly, shear strength parameters (for example the friction angle measured in shear box testing) relate to mass shear failure and do not provide a measure of resistance to particle-by-particle erosion. With a D50 of approximately 0.1mm to 0.2mm, these soils lie close to the most readily erodible particle size range for natural sediments.

The critical velocities quoted above from Soulsby (1997) are expressed as depth-averaged values, whereas the propeller jet velocities calculated in Section 8 are near-bed / jet-axis values, so the two are not strictly like-for-like.

Based on the characteristic soil type of silty-sand, and considering the effects of slope, the minimum flow velocity to instigate scour is expected to be between 0.3m/s and 0.35m/s. This threshold establishes susceptibility to erosion only.

5.6.2 Uncertainties

The assessment above is a screening assessment based on published thresholds for the onset of sediment motion (Soulsby, 1997; Briaud, Govindasamy and Shafii, 2017). These thresholds identify the velocity at which individual grains begin to move, and they are conservative when read as an indicator of damage: exceedance means that some sediment can be mobilised, not that significant erosion of the slope will develop. They provide no information on the rate at which erosion would proceed, on the depth or extent of any scour feature, or on the behaviour of the deeper spit material once a feature begins to form.

Calculating the actual erosion exactly is very difficult. No published method is available for the governing situation at Whiteness Head: an azimuthing propeller jet acting intermittently, at varying position and power, on a 1V:6H slope of silty fine sand.

Furthermore, several additional factors may contribute to a greater resistance to erosion than considered in the adopted theoretical assessment:

- Fines content: Mixed sand-mud sediments can exhibit erosion thresholds significantly higher than those of clean, non-cohesive sands. Previous studies have shown that the addition of relatively small quantities of fines may substantially increase the critical shear stress required for erosion (Van Ledden, 2003; Winterwerp & Van Kesteren, 2004).
- Organic matter and vegetation effects: Root reinforcement and the presence of organic matter can increase sediment stability. Temmerman et al. (2007) and Schwarz et al. (2015) demonstrated that root-reinforced sediments may remain stable under hydraulic loading

conditions that would otherwise result in complete mobilisation of equivalent clean sand deposits.

- Surface armouring: Natural spits can develop an armour layer consisting of gravel, shell fragments, and other coarse material. Such armouring increases the critical hydraulic conditions required to initiate erosion and can provide significant protection against local scour.

Although these factors indicate the potential for greater erosion resistance than assumed in the present assessment, the available literature does not readily provide a robust quantitative framework for incorporating these effects into a site-specific erodibility analysis. Consequently, it is not currently possible to derive a reliable quantitative reduction in erosion risk based on these factors alone.

Given the limitations of the available theoretical approaches and the uncertainty associated with the actual erodibility of the spit, this report does not attempt to predict scour depths or erosion rates quantitatively. Instead it is recommended to adopt a precautionary buffer-based management strategy.

Under this approach, the existing buffer width between the area of concern and the critical infrastructure should be monitored periodically. The implementation of scour protection measures should only be considered if monitoring indicates a significant reduction in the available buffer.

Recommendations are set out in Section 10 (Buffer and Monitoring Recommendations).

6 Port Layout

Ardersier Port (Scotland) Limited have provided Haskoning with PDF and CAD versions of the proposed layout post dredging (indicated below). It is reasonable to expect that port operations will endeavour to maintain a healthy margin between vessels and the spit at all times. Comments from Ardersier Port (Scotland) Limited's deputy harbourmaster imply the vessels will not typically have any reason to operate within 30m of the toe of the dredged slope.

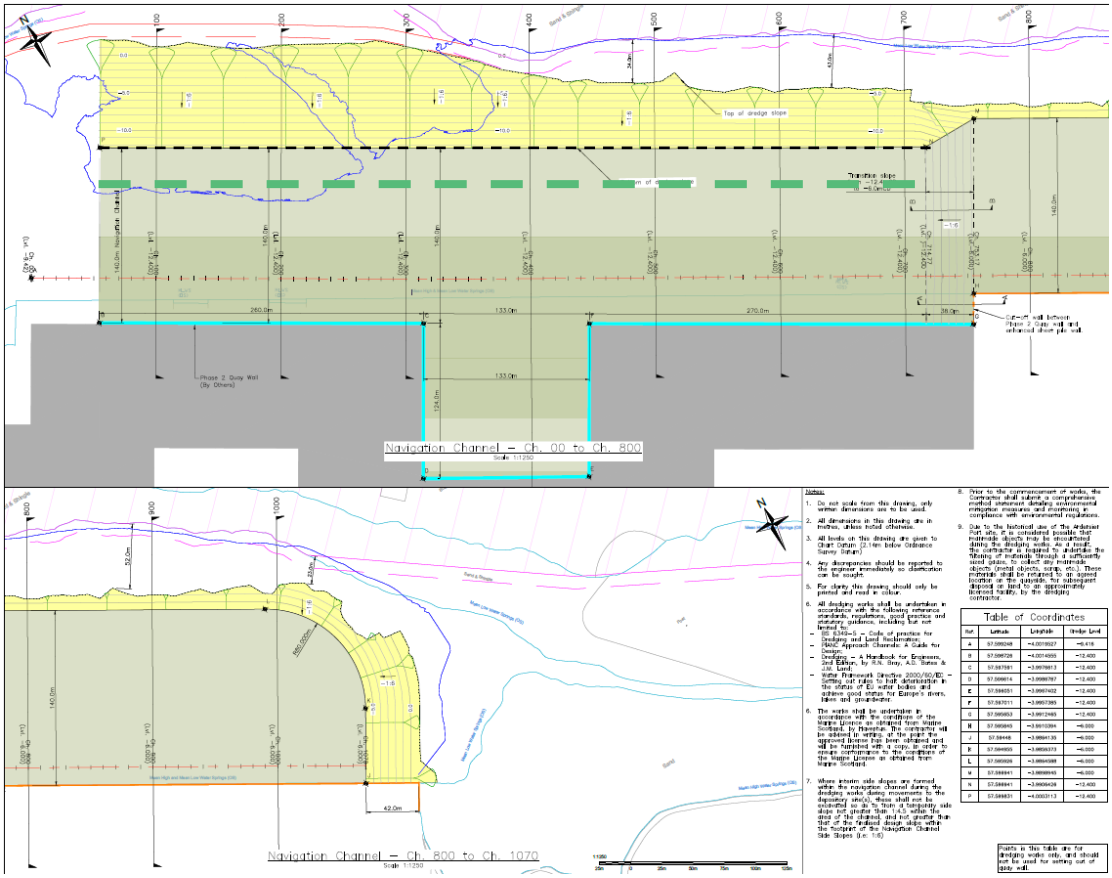


Figure 6-1: Proposed dredged layout, with a dashed green line indicating operational extents for regular manoeuvres

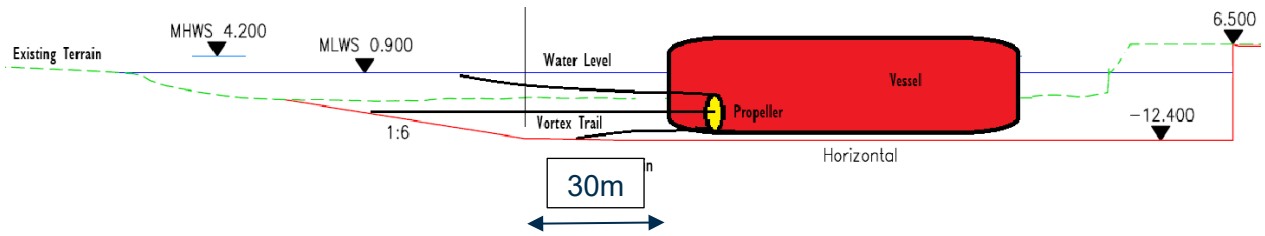


Figure 6-2: An indicative cross-sectional sketch outlining the position of a vessel in the Inner Harbour (-12.4mCD) relative to Whiteness Head

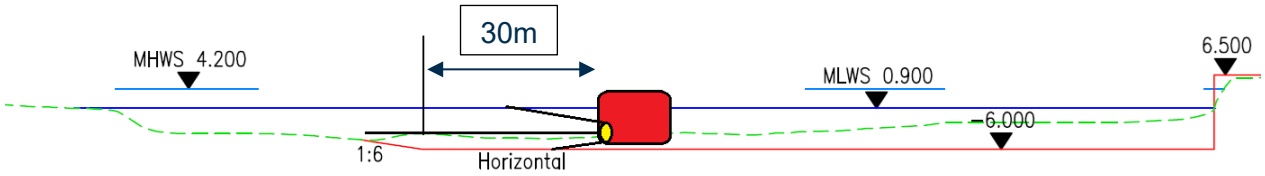


Figure 6-3: An indicative cross-sectional sketch outlining the position of a vessel in the Inner Harbour (-6m CD) relative to Whiteness Head

7 Vessel Characteristics

Haskoning have collated vessel characteristics using a combination of information provided by the Ardersier Port Harbourmaster, past project experience, internal ship database information and open-source online sources (for example marketing information from tug ship providers). It is not possible to definitely outline in advance every vessel that will visit the port. Instead, our team have endeavoured to consider the range of likely vessels and select a realistic yet conservative "worst-case" for the effects of propellor scour.

7.1 Harbourmaster Comments

The following comments were provided by the Harbourmaster for Ardersier Port:

"…it's extremely different to say for sure what type, size or propulsion capability vessels that may visit Ardersier Port will have.

- *Vessel sizes could vary, however a maximum LOA of around 270m is a fair assumption for now, with a breadth of 65m. Drafts could vary from -4m to -10m.*
- *Vessels that are used to transport wind farm components are generally single or double propeller propulsion (non-nozzle) however all wind farm installation vessels are generally azipod fitted.*
- *Propeller diameter could be as large as 6m.*
- *All large vessels, other than installation vessels, their arrival and departure would be assisted by harbour tugs, therefore prop wash on these vessels would be minimal. Tugs generally have a draft of around 5-6m, with azipod propulsion systems. Their prop diameter is approximately 3m. Tugs would be around 70T Bollard Pull (BP)."* - Donald

And also from the deputy harbourmaster:

"Tugs we have used to date and will continue to use are on or around the 70t bollard pull, azi stern drive (USD) type with an average length of 23m and max draught of 5.5m. The 2 longest tug we have had in here is 32m, however they have a BP of 65t each. Tugs are operated by Targe Towing and Boluda Towage. A high percentage of the time, the tugs are for insurance purposes and will not be used for manoeuvring.

A heavy lift vessel of 255m length 57m beam and 10m draught in the centre of the channel. If 2 x tugs are required to push her on to the quay then even with the longest tug there is over 30m from the stern of the tug to the edge of the channel. " – Rod MacLeman, Ardersier Port (Scotland) Limited

Ardersier Port (Scotland) Limited provided vessel information for the following tug vessels:

- Balmerino

- Camperdown
- Inchcolm
- Queensferry
- VB Lloydsman
- VB Strathdee

Based on Haskoning's desktop review of these tug vessels the Camperdown was selected as the design tug vessel.

Table 7-1: Tug Parameters based on online sources

Vessel Type	Camperdown
Bollard Pull (BP)	85 t
Total power	5050 kW
Number of azipods	2
Prop. diameter D	2.8 m
Length Overall (LOA)	29.4 m
Beam	13.3 m
Draft	5.75 m

For the inner harbour (-6m CD) Haskoning have considered a small cargo vessel and an offshore Platform Supply Vessel (PSV). Ardersier Port (Scotland) Limited's harbourmaster provided the characteristics of the Western Rock general cargo vessel (IMO: 9827554) as a typical example of a small cargo vessel, as outlined in the following table.

Table 7-2: Characteristics of a small cargo vessel, as provided by Ardersier Port (Scotland) Limited, based on the Western Rock

Vessel Type	Small Cargo
Deadweight	3400 t
Total power	1325 kW
Number of propellers	1
Prop. diameter D	3
Length Overall (LOA)	92.9
Beam	15
Draft	5

7.2 Haskoning Experience

From recent experience, Haskoning have found realistic parameters for a range of tug sizes.

Table 7-3: Tug Parameters based on recent Haskoning experience

Vessel Type	Harbour ASD Tug	Harbour ASD Tug	Harbour ASD Tug
Bollard Pull (BP)	47 t	60 t	80 t
Total power	4024 kW	5000 - 5150 kW	6000 kW
Number of propellers	2	2	2
Prop. diameter D	2.6 m	2.8 m	3.0 m
Distance between props	4.8 m	5 – 5.2 m	5.3 m
Distance to stern (m)	2.2 m	2.5 m – 2.8m	2.9 m
Length Overall (LOA)	28.7 m	30.6 – 31.5 m	33.9 m
Beam	10.43	10.6 – 11.5 m	11.5 m
Depth	4.6 m	5.0 – 6.1 m	6.1 m
Draft	3 m	3.8 – 4.4 m	4.4 m
Distance of prop. tip to keel	0.5 m	0.5 m	0.5 m

7.3 Online Sources

As a verification step, Haskoning have conducted some research of tug parameters from open-source online sources.

Table 7-4: Tug Parameters based on online sources

Vessel Type	Damen ASD 2312	Navnautik ASD 36m	Navnautik ASD 37m
Bollard Pull (BP)	70 t	70 t	70 t
Total power	3804 kW	3676 kW	-
Number of propellers	2	2	2
Prop. diameter D	2.8 m	-	2.7 m

Length Overall (LOA)	22.8 m	35.6 m	37.7 m
Beam	12.0 m	11.0 m	11.0 m
Draft	5.6 m	4.6 m	5.0 m

Haskoning have also researched the characteristics of a small cargo vessel and an offshore Platform Supply Vessel (PSV) which are typical of the vessels operating in the Inner Harbour (-6mCD). Haskoning obtained the characteristics of a typical cargo vessel (Briese Schiffart's "Pride") and a typical PSV (the Jensen 2800 designed by Crowley) which are given in Table 7-6.

Table 7-5: Vessel Characteristics for typical vessels using the Inner Harbour (-6m CD)

Vessel Name	**Pride**	**Jensen 2800**
Vessel Type	**General Cargo**	**PSV**
Deadweight	3000 t	2800 t
Total power	1125kW	2 x 1650 kW
Number of propellers	1	2
Prop. diameter D	2.8 - 3.4m (assumed)	2.5 (assumed)
Length Overall (LOA)	88.5	70
Beam	11.35	16.5
Draft	4.94	4.8

7.4 Summary Table

Haskoning have reviewed the vessel parameters from all available sources and summarised those relevant to a propellor scour assessment in the following tables, for the Inner Harbour (-12.4mCD) and the Inner Harbour (-6mCD). Following the initial submission of the report, Ardersier Port (Scotland) Limited provided Haskoning with additional information on the Tugs that will be of use within the harbour, see Section 9 for more information. Using this information, the design tug vessel parameters were based on the Camperdown.

Table 7-6: *Vessel information summary table (Inner Harbour (-12.4mCD))*

Vessel Parameter	**Large Transport Vessels** (Tug Assisted)	**Large Installation Vessels** (not Tug assisted)	**ASD Tug - 85t BP**
LOA	270m	270m	29.4m
Breadth	65m	65m	13.3m
Draft	-10m	-10m	-5.75m
Propeller Type	Single or Double Prop (non-ducted)	Azipods (4No.)	Azipods (2No.)
Thrusters	Small compared to tug forces	Small compared to tug forces	
Propeller shaft spacing	Single prop. N/A Double prop. 15.0m	Port / starboard: 40m forward / aft: 30m	6.65m (assumed)
Prop. Diameter	Up to 6m	Up to 6m	2.8m
Engine Power	Single: 18MW, Double: 2x15MW	Azipods: 4x8MW	5050kW
Power applied	15%	50%	50%
Max permissible Vessel Speed	1.0m/s	1.0m/s	1.0m/s
Distance to the toe edge of the dredged slope	30m	30m	30m

Table 7-7: *Vessel information summary table (Inner Harbour (-6mCD))*

Vessel Parameter	ASD Tug - 85t BP	Cargo vessel	Platform Supply Vessel (PSV)
LOA (m)	29.4m	92.9	70
Breadth (m)	13.3m	15	16.5
Draft (m)	-5.75m	-5	-4.8
Propeller Type	Azipods (2No.)	Single (free)	twin azimuthing stern drives (Z-drives)
Thrusters		350 kW (bow), 250 kW (stern)	2 x 550 kW
Propeller shaft spacing	6.65m (assumed)	-	7m (assumed)
Prop. Diameter	2.8m	3m	2.5m
Engine Power	5050kW	1325 kW	2 x 1650 kW
Power applied	50%	15%	15%
Max permissible Vessel Speed	1.0m/s	1.0m/s	1.0m/s
Distance to the toe edge of the dredged slope	30m	30m	30m

8 Scour Assessment (Worst Case Scenario)

8.1 Introduction

This section presents the initial scour assessment of Whiteness Head based on an estimation of the current velocity induced by vessel propellers at the slope of the sand spit. It is split into two sub-sections following this introduction:

8.2 Discussion of design cases for scour and selection of the dominant design cases, and
8.3 Calculations to indicate propeller jet velocities for those dominant design cases (including sensitivity checks).

This section presents a worst case design scenario, with vessels operating at 50% power (as recommended by PIANC Working Group 180 guidance) and jets directed towards the spit. To give a feel for the range of possible outcomes, a more realistic scenario is presented in Section 9.

8.2 Design Cases

Ardersier Port operations will include different vessel classes (with different power outputs, propellor sizes and drafts), operating at various distances from the dredged slope. For the purpose of this assessment the port is notionally divided into two areas; the “Inner Harbour (-12.4mCD)” with a dredged level of -12.4mCD and the “Inner Harbour (-6mCD)” with a dredged level of -6mCD.

Haskoning have considered several theoretical scenarios to identify and assess the “worst case(s)” for propellor scour for the Inner Harbour (-12.4mCD) and the Inner Harbour (-6mCD).

In all scenarios, it will be considered that the propellor is pointing directly towards the dredged slope, perpendicular to the line of the quay wall.

For all design cases a conservative scenario for the water level is employed (i.e. Mean low Water Springs (MLWS)) which provides the minimum distance to the spit.

8.2.1 Inner Harbour (-12.4mCD)

In the Inner Harbour (-12.4mCD), Haskoning have considered two scenarios:

A1. A large vessel operating under its own propulsion
A2. A tug guiding a large vessel

8.2.1.1 Design Case A1

For the large vessel design case, Haskoning have chosen to consider an unassisted offshore wind installation vessel with an azipod thruster system. This has been chosen over a vessel with a single or double propellor propulsion system for the following reasons:

- Due to the lack of tug assistance the power applied per propeller is much higher for the unassisted vessel (8MW x 50% = 4MW compared to 15MW x 15% = 2.25MW.
- The directionality of the azipod thrusters is far more likely to be directed towards Whiteness Head, considering the large vessel dimensions and manoeuvring space within the harbour.

8.2.1.2 Design Case A2

Haskoning also considered whether a tug vessel could be the dominant design case in the Inner Harbour (-12.4mCD). We have concluded that the tug vessel will not be the dominant design case because:

a) The power applied per propellor is smaller than the large vessel (5050kW x 50% = 2525kW compared to 8MW x 50% = 4MW)
b) The draft of the tug (-5.75m) is much smaller than the draft of the large vessel (-10m) and therefore the tug azipods are further from the bed / slope than the large vessel.

8.2.1.3 Selected Design Case for the Inner Harbour (-12.4mCD)

Haskoning have concluded that Design Case A1 (an unassisted offshore wind installation vessel) is the dominant Design Case for the Inner Harbour (-12.4mCD).

8.2.2 Inner Harbour (-6mCD)

In the Inner Harbour (-6mCD), Haskoning have considered three scenarios:

B1. A tug providing navigation assistance to a small vessel (barge, general cargo or PSV)
B2. A small general cargo vessel operating under its own propulsion
B3. A small PSV vessel operating under its own propulsion

8.2.2.1 Design Case B1

For the tug vessel design case, a theoretical tug vessel with an 85t BP rating will be considered. The draft of the vessel (-5.75m) is similar to other vessels using the Inner Harbour (-6mCD), but the power output to the thrusters is relatively high (5050kW x 50% = **2525kW**).

8.2.2.2 Design Case B2

For a small cargo vessel with a single propeller and a bow thruster the draft is similar to a tug but the power output from the main propellor is relatively low (1.325MW x 15% = **0.2MW** versus 3MW). Even considering the bow thruster of 0.35MW at full power, this is unlikely to dominate when compared to the tug scenario.

8.2.2.3 Design Case B3

For a PSV with two propellors and bow thrusters the draft is similar to a tug but the power output from the main propellor is relatively low (1.65MW x 15% = **0.25MW** versus 3MW). Even considering the bow thruster of 0.55MW at full power, this is unlikely to dominate when compared to the tug scenario.

8.2.2.4 Selected Design Case for the Inner Harbour (-6mCD)

Haskoning have concluded that Design Case B1 (a tug assisting a vessel) is the dominant Design Case for the Inner Harbour.

8.3 Maximum Propeller Induced Current Velocities

8.3.1 Calculation Methodology

For the selected Design Cases the maximum current velocities at the channel bottom and at the sand spit induced by the azipod thruster system are calculated using the Dutch and German methods outlined in PIANC WG 180 (PIANC Working Group 180, 2015) which inform Haskoning's opinion of whether scour is likely to occur. For each harbour area this section presents the area specific assumptions and the calculation results for a baseline scenario and the sensitivity checks.

Assumptions common to both the Inner Harbour (-12.4mCD) and Inner Harbour (-6mCD) are:

- The azipod thruster jets are assumed to act independently and be directed towards the sand spit during manoeuvring i.e. the flow jets of multiple propellers do not combine.
- Possible rudder effect is included (based on one central rudder per azipod)
- It is sufficient to check the velocity at the level of the axis of the propeller and the bed level i.e. no intermediate positions have been checked.
- The factor of confinement is 1.0 (no confinement of the jet due to close proximity to the quay is assumed i.e. there is free dispersion of the propellor jet as it travels from the vessel towards the spit).
- A tide level of Mean Low Water Springs (MLWS) = +0.9mCD and water density of 1025kg/m^3 applies throughout.

8.3.2 Inner Harbour (-12.4mCD) Assessment

8.3.2.1 Assumptions

- For the propeller tip to keel distance $D_p/2+0.1$ (where D_p = propeller diameter) is assumed.
- Propeller type is Free.
- a bed level of -12.4mCD applies throughout.

8.3.2.2 Baseline Scenario

The results in this sub-section are intended to reflect a realistic “worst case” scenario for scour based on a conservative interpretation of available information regarding; the vessel thrusters, soils, and typical navigational practices.

Table 8-1: Maximum current velocities for the offshore wind installation vessel (not tug assisted)

Location	Inner Harbour (-12.4mCD)
Distance of propeller axis to lateral boundary (m)	30
%-age of power applied	50%
Max. bed velocity (at channel bottom)	1.5 m/s (dutch) 2.9 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	2.8 m/s (dutch) 3.7 m/s (german)

The maximum velocity for a distance of 30m from the spit is up to 2.9m/s at the channel bottom and up to 3.7m/s along the slope of the spit during manoeuvring operations, induced by the Large Installation vessel. The flow at the spit is highly turbulent due to the impingement of the propeller jet on the spit, resulting in a recirculation zone along the seabed. Also note that the German Method usually results in higher velocities since it does not account for the strong spreading function as the Dutch Method does.

All velocities (at channel bottom and at the 1:6 slope) are beyond 0.3-0.35m/s, i.e. the threshold for erosion of the existing spit slope. Thus, some erosion (especially of loose surface deposits) is expected to occur without any bottom or slope protection. Due to the uncertainties described in Section 5.6.2 it is unclear how much erosion will occur, especially of the subsurface layers of the spit.

Therefore, it is not possible using desk based methods to conclude if the quantity of erosion would require dedicated scour protection. In our opinion, a suitably cautious approach would be to plan for a buffer, monitor the slope for any scour that may occur, and to remediate and/or install targeted protection should the rate of erosion requires it. This is further expounded in Section 10.

8.3.2.3 Sensitivity Checks

Increased Distance Scenario

The results in this sub-section are intended to reflect a modification of the baseline scenario, accounting for operational restrictions which control navigation. The underlying logic is that if vessel movements are restricted to be relatively far away from Whiteness Head, might the potential risk of scour be mitigated? Haskoning have investigated an increase in the offset distance from 30m to 50m, which we consider a reasonable maximum following conversations with the harbourmaster. This considers the channel width of 140m, the vessel beam and the room required to manoeuvre on and off the berth.

Table 8-2: Maximum current velocities for the large installation vessel (not tug assisted)

Location	Inner Harbour (-12.4mCD)
Distance of propeller axis to lateral boundary (m)	50
%-age of power applied	50%
Max. bed velocity (at channel bottom)	1.5 m/s (dutch) 2.9 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.70m/s (dutch) 2.2 m/s (german)

Note that although the velocities are reduced for a larger distance from the spit, they are still relatively large: up to 2.2m.s. An even larger distance to the spit (>50m) is not considered practically achievable.

All velocities (at channel bottom and at the 1:6 slope) are beyond 0.3-0.35m/s, i.e. the threshold for erosion of the existing spit slope. Thus, some erosion (especially of loose surface deposits) is expected to occur without any bottom or slope protection, independent of the chosen distance of 30m or 50m from the spit slope. Due to the uncertainties described in Section 5.6.2 it is unclear how much erosion will occur, especially of the subsurface layers of the spit.

It is therefore concluded that operational controls to maintain a minimum distance from vessels to the spit slope alone would not adequately mitigate the risk of scour. A buffer and monitoring approach therefore seems advisable, see Section 10.

Reduced Power Scenarios

The results in this sub-section are intended to reflect a modification of the baseline scenario, accounting for operational restrictions which control navigation. The underlying logic is that if vessel power applied is restricted within the harbour, might the potential risk of scour be mitigated?

The propulsion power used by vessels within the harbour channels is dependent on factors such as vessel loading conditions, environmental conditions, traffic constraints, and manoeuvring requirements. To account for this variability, a sensitivity assessment was undertaken varying the applied propulsion power ranging from 10% to 40%. The results can be found in Table 8-3.

Table 8-3 Maximum current velocities when the %-age of applied main power varies between 10 - 40 % dor the Large Installation Vessel (not tug assisted)

Location	Inner Harbour (-12.4mCD)
Distance of propeller axis to lateral boundary (m)	30
%-age of power applied	**10%**
Max. bed velocity (at channel bottom)	0.90 m/s (dutch) 1.70 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.70 m/s (dutch) 2.20 m/s (german)
%-age of power applied	**20%**
Max. bed velocity (at channel bottom)	1.10 m/s (dutch) 2.20 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	2.10 m/s (dutch) 2.70 m/s (german)
%-age of power applied	**30%**
Max. bed velocity (at channel bottom)	1.30 m/s (dutch) 2.5 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	2.40 m/s (dutch) 3.10 m/s (german)
%-age of power applied	**40%**
Max. bed velocity (at channel bottom)	1.40 m/s (dutch) 3.0 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	2.60 m/s (dutch) 3.40 m/s (german)

The sensitivity analysis shows that even for a 10% applied power (which is well below the recommended value of 50% based on published PIANC guidance, but within the typically 10-20% applied power for berthing procedures as advised by harbourmaster) the predicted velocities at the spit slope are still above 1m/s, i.e. well above the erosion threshold.

It is therefore concluded that operational controls to limit percentage power applied by vessel thrusters in the harbour alone would not adequately mitigate the risk of scour. A buffer and monitoring approach therefore seems advisable, see Section 10.

Increased Distance & Reduced Power Scenarios

A sensitivity assessment was undertaken to combine the possibility of navigational restrictions, limiting both the position of, and power applied by, manoeuvring vessels. The results can be found in Table 8-3.

Table 8-4 Maximum current velocities when the %-age of applied main power varies between 10 - 40 % dor the Large Installation Vessel (not tug assisted)

Location	Inner Harbour (-12.4mCD)
Distance of propeller axis to lateral boundary (m)	50
%-age of power applied	**10%**
Max. bed velocity (at channel bottom)	0.90 m/s (dutch) 1.70 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.0 m/s (dutch) 1.30 m/s (german)
%-age of power applied	**20%**
Max. bed velocity (at channel bottom)	1.10 m/s (dutch) 2.20 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.30 m/s (dutch) 1.70 m/s (german)
%-age of power applied	**30%**
Max. bed velocity (at channel bottom)	1.30 m/s (dutch) 2.5 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.40 m/s (dutch) 1.90 m/s (german)

%-age of power applied	40%
Max. bed velocity (at channel bottom)	1.40 m/s (dutch) 3.0 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.60 m/s (dutch) 2.10 m/s (german)

The sensitivity analysis shows that even for a 10% applied power the predicted velocities at the spit slope are still above 1m/s, i.e. well above the erosion threshold of 0.35m/s.

As mentioned prior, a 10% applied power is well below the recommended value of 50% based on published PIANC guidance but within the typically 10-20% applied power for berthing procedures as advised by harbourmaster.

It is therefore concluded that operational controls on positioning and percentage power applied combined would not adequately mitigate the risk of scour. A buffer and monitoring approach therefore seems advisable, see Section 10.

8.3.3 Inner Harbour (-6mCD) Assessment

8.3.3.1 Assumptions

- For the propeller tip to keel distance 0.5m is assumed.
- Propeller type is assumed Free or Ducted for the Tug (worst case is chosen).
- a bed level of -6.0mCD applies throughout.

8.3.3.2 Baseline Scenario

The results in this sub-section are intended to reflect a realistic “worst case” scenario for scour based on a conservative interpretation of available information regarding; the vessel thrusters, soils, and typical navigational practices.

Table 8-5: Maximum current velocities for the Tug

Location	Inner Harbour (-6mCD)
Distance of propeller axis to lateral boundary (m)	30
%-age of power applied	50%
Max. bed velocity (at channel bottom)	3.28 m/s (dutch) 3.07 m/s (german)

Max. velocity at slope of sand spit (at level of propellers)	1.65 m/s (dutch) 1.53 m/s (german)

The tables demonstrate that for an applied main power fraction of 50% for a tug in the Inner Harbour (-6mCD) the velocities at the slope are 1.53 – 3.28m/s.

These values are significantly above the erosion threshold of 0.35m/s. A buffer and monitoring approach therefore seems advisable, see Section 10.

8.3.3.3 Sensitivity Checks

Increased Distance Scenario

The maximum current velocities at the channel bottom and at the sand spit are calculated by the Dutch and German methods outlined in PIANC WG 180 (PIANC Working Group 180, 2015). In Table 8-5 the velocities are provided for the case of distances to the lateral boundary of 50m for the tug vessel.

Table 8-6: Maximum current velocities for the Tug

Location	Inner Harbour (-6mCD)
Distance of propeller axis to lateral boundary (m)	50
%-age of power applied	50%
Max. bed velocity (at channel bottom)	3.28 m/s (dutch) 3.07 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	0.99 m/s (dutch) 0.92 m/s (german)

These values are significantly above the erosion threshold of 0.35m/s.

Although the velocities are reduced for a larger distance from the spit, they are still relatively large: up to 3.28m.s. An even larger distance to the spit (>50m) is not considered practically achievable.

Thus, some erosion (especially of loose surface deposits) is expected to occur without any bottom or slope protection, independent of the chosen distance of 30m or 50m from the spit slope. Due to the uncertainties described in Section 5.6.2 it is however unclear how much erosion, especially of the more erosion resistant underlayers of the spit, will occur

It is therefore concluded that operational controls to maintain a minimum distance from vessels to the spit slope alone would not adequately mitigate the risk of scour. A buffer and monitoring approach therefore seems advisable, see Section 10.

Reduced Power Scenario

The results in this sub-section are intended to reflect a modification of the baseline scenario, accounting for operational restrictions which control navigation. The underlying logic is that if vessel power applied is restricted within the harbour, might the potential risk of scour be mitigated?

The propulsion power used by vessels within the harbour channels is dependent on factors such as vessel loading conditions, environmental conditions, traffic constraints, and manoeuvring requirements. To account for this variability, a sensitivity assessment was undertaken varying the applied propulsion power ranging from 10% to 40%. The results can be found in Table 8-7.

Table 8-7 Maximum current velocities when the %-age of applied main power varies between 10 - 40 % for the Tug

Location	Inner Harbour (-6mCD)
Distance of propeller axis to lateral boundary (m)	30
%-age of power applied	**40%**
Max. bed velocity (at channel bottom)	3.04 m/s (dutch) 2.85 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.53 m/s (dutch) 1.42 m/s (german)
%-age of power applied	**30%**
Max. bed velocity (at channel bottom)	2.77 m/s (dutch) 2.59 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.39 m/s (dutch) 1.29 m/s (german)
%-age of power applied	**20%**
Max. bed velocity (at channel bottom)	2.42 m/s (dutch) 2.25 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.22 m/s (dutch) 1.13 m/s (german)

%-age of power applied	**10%**
Max. bed velocity (at channel bottom)	1.92 m/s (dutch) 1.79 m/s (german
Max. velocity at slope of sand spit (at level of propellers)	0.96 m/s (dutch) 0.90 m/s (german)

The sensitivity analysis shows that even for a 10% applied power (which is well below the recommended value of 50% based on published PIANC guidance but within the typically 10-20% applied power for berthing procedures as advised by harbourmaster) the predicted velocities at the spit slope are still approximately 1m/s, i.e. well above the erosion threshold.

It is therefore concluded that operational controls to limit percentage power applied by vessel thrusters in the harbour alone would not adequately mitigate the risk of scour. A buffer and monitoring approach therefore seems advisable, see Section 10.

Increased Distance & Reduced Power Scenarios

A sensitivity assessment was undertaken to combine the possibility of navigational restrictions, limiting both the position of, and power applied by, manoeuvring vessels. The results can be found in Table 8-8.

Table 8-8 Maximum current velocities when the %-age of applied main power varies between 10 - 50 % for the Tug

Location	**Inner harbour (-6m CD), 50m to lateral boundary**
Distance of propeller axis to lateral boundary (m)	50
%-age of power applied	**40%**
Max. bed velocity (at channel bottom)	3.04 m/s (dutch) 2.85 m/s (german
Max. velocity at slope of sand spit (at level of propellers)	1.53 m/s (dutch) 1.42 m/s (german)
%-age of power applied	**30%**
Max. bed velocity (at channel bottom)	2.77 m/s (dutch)

	2.59 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.39 m/s (dutch) 1.29 m/s (german)
%-age of power applied	**20%**
Max. bed velocity (at channel bottom)	2.42 m/s (dutch) 2.25 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.22 m/s (dutch) 1.13 m/s (german)
%-age of power applied	**10%**
Max. bed velocity (at channel bottom)	1.92m/s (dutch) 1.79m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	0.96 m/s (dutch) 0.90 m/s (german)

The sensitivity analysis shows that even for a 10% applied power the predicted velocities at the spit slope are still approximately 1m/s, i.e. well above the erosion threshold of 0.35m/s.

As mentioned prior, a 10% applied power is well below the recommended value of 50% based on published PIANC guidance but within the typically 10-20% applied power for berthing procedures as advised by harbourmaster.

It is therefore concluded that operational controls on positioning and percentage power applied combined alone would not adequately mitigate the risk of scour. A buffer and monitoring approach therefore seems advisable, see Section 10.

Other Vessel Types

As part of the sensitivity checks for the Inner Harbour (-6mCD) Haskoning undertook initial checks on other vessel types (small cargo vessel, PSV) to double check the assumption that the tug was the dominant design case. The calculations indicated this was indeed the case, but for the sake of brevity, these results are not reported.

9 Scour Assessment (More Realistic Scenario)

9.1 Introduction

After submission of the worst case scenario, Ardersier Port (Scotland) Limited provided Haskoning with additional information which assisted Haskoning in assessing a less conservative scenario that better reflects typical day-to-day operations based on the following:

- Revised tug vessel thruster orientation
- A detailed description of the envisaged berthing manoeuvring process, allowing for
    - Revised vessel berthing speeds
    - Revised minimum distances from Whiteness Head spit

This section of the report presents the background and Haskoning's assessment of this more realistic design scenario. The structure of this section following this introduction is as follows:

9.2 A description of the revised design cases for the dominant situations
9.3 Calculations to indicate propeller jet velocities for the revised design cases.

9.2 Revised Design Cases

The same selected design cases from Section 8.2 were adapted for use in this Section. For ease of reference these were:

- For the inner harbour (-12.4mCD) an unassisted large wind farm installation vessel
- For the inner harbour (-6.0mCD) a tug assisted small vessel (e.g. barge)

9.2.1 Inner harbour (-12.4mCD): Large Installation Vessel

The Inner Harbour (-12.4mCD) selected design case was modified in the following ways.

During vessel manoeuvres the wind speed and direction is an important factor. A strong wind requires more power applied to the thrusters to counter wind forces pushing the vessel. The harbourmaster and pilots take account of the forecasted wind speed when planning manoeuvres. The vessel will only be allowed to enter the harbour and berth when the wind has dropped to a level which is suitably low risk.

The harbourmaster has advised that current operational experience is that vessel speeds during berthing procedures are typically much lower than 1m/s, i.e. in the range of cm/s. For the more realistic scenario therefore a berthing speed of 0.1m/s and a corresponding power applied of 10-20% of installed capacity for the large installation vessel is assumed.

Figure 9-1 shows the approach configuration advised by the harbourmaster. This indicates that the vessel will align itself no more than 30m from the quayside on its approach. This means that the distance from its props to the toe of the dredge slope is 45m (minimum).

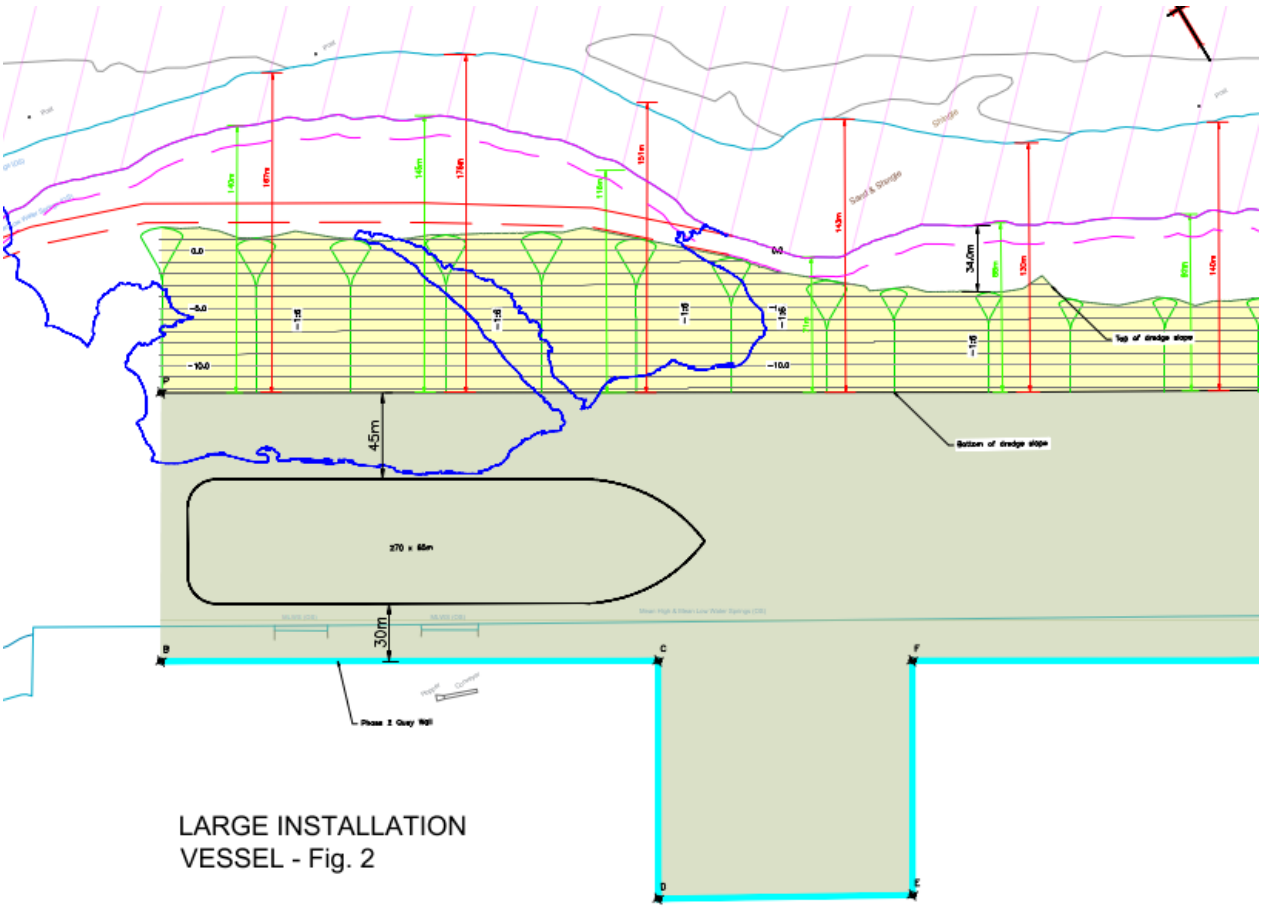


Figure 9-1 Minimum distance to spit for Large Installation Vessel

The revised design vessel parameters are presented in Table *9-1*.

Table 9-1*: Design vessel information (Inner Harbour (-12.4mCD))*

Vessel Parameter	**Large Installation Vessels** (not Tug assisted)
LOA	270m
Breadth	65m
Draft	-10m
Propeller Type	Azipods (4No.)

Thrusters	Small compared to tug forces
Propeller shaft spacing	Port / starboard: 40m, forward / aft: 30m
Prop. Diameter	Up to 6m
Engine Power	Azipods: 4x8MW
Power applied	15%
Max permissible Vessel Speed	0.1m/s
Distance to the toe edge of the dredged slope	45m

9.2.2 Inner harbour (-6.0mCD): Tug

The Inner Harbour (-6.0mCD) selected design case was modified in the following ways.

Similar to the Inner Harbour (-12.4mCD) design case, the harbourmaster has advised that current operational experience is that vessel speeds during berthing procedures are typically much lower than 1m/s, i.e. in the range of cm/s. For the more realistic scenario therefore a berthing speed of 0.1m/s and a corresponding power applied of 10-20% of the installed capacity for the tug vessel is assumed.

The thruster orientation for tugs was previously assumed to be parallel to the seabed, in line with the figures published in PIANC design guidance (PIANC Working Group 180, 2015). However, the updated vessel characteristics provided by the harbourmaster indicate that the azipods are generally angled at between 4-6 degrees upwards from horizontal. Over large distances (considering the 30m+ distance to the slope and the 1:6 slope over a height of 6m+) the effects of this angle are considered relevant to the calculated flow velocities.

The maximum size of barge that might enter the Inner Harbour in the -6mCD area is 110m by 25m. These will be tug assisted. Figure 9-2 shows the closest position of such a barge and tugs to the dredge slopes when being pushed onto the berth as being 57m.

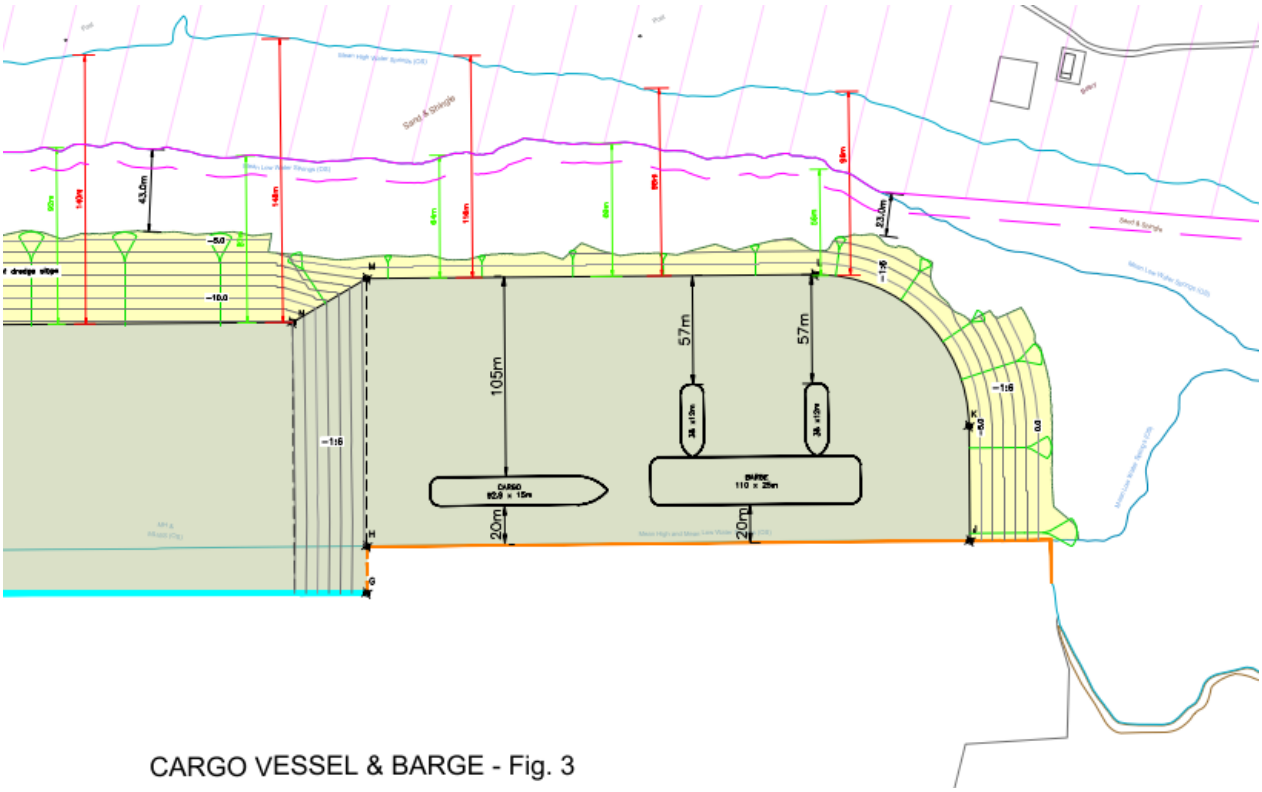


Figure 9-2 Minimum distance to spit for Cargo Vessel and Barge

The revised design vessel parameters are presented in Table 9-2.

Table 9-2*: Design vessel information (Inner Harbour (-6mCD))*

Vessel Parameter	ASD Tug - 85t BP
LOA (m)	29.40
Breadth (m)	13.30
Draft (m)	-5.75
Propeller Type	Azipods (2No.)
Propeller shaft spacing	6.65m
Prop. Diameter	2.8m
Engine Power	5050kW
Power applied	15%
Max permissible Vessel Speed	0.1m/s
Distance to the toe edge of the dredged slope	57m

9.3 Maximum Propeller Induced Current Velocities

9.3.1 Calculation procedure and assumptions

The calculation procedure and employed assumptions are consistent with Section 8.3 except for the following modifications:

- These calculations included a 4° upwards angle for the tug azipods (conservative assumption based on 4° -6° range). Other jet angles were not investigated.
- The spreading distance was calculated in relation to the distance from the vessel to the spit.
- A validation factor was applied to account for whether the jet stays submerged or reaches the surface before the spit. If it reaches the surface, the result is not valid.
- All calculations are based on MLWS (i.e. minimum distance to spit). Calculations for higher water levels (which are less conservative due to longer distances to the spit) were not investigated.

9.3.2 Inner Harbour (-12.4mCD) Assessment

The calculation results for the Inner Harbour (-12.4mCD) are provided in Table 9-3.

Table 9-3. Maximum current velocities for the Large Installation Vessel (not tug assisted)

Location	Inner Harbour (-12.4mCD)
Distance of propeller axis to the dredged slope (m)	45
%-age of power applied	**10%**
Max. bed velocity (at channel bottom)	0.84 m/s (dutch) 1.70 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.07 m/s (dutch) 1.43 m/s (german)
%-age of power applied	**15%**
Max. bed velocity (at channel bottom)	0.96 m/s (dutch) 1.95 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	1.23 m/s (dutch) 1.67 m/s (german)
%-age of power applied	**20%**
Max. bed velocity (at channel bottom)	1.05 m/s (dutch) 2.15 m/s (german)

Max. velocity at slope of sand spit (at level of propellers)	1.35 m/s (dutch) 1.80 m/s (german)

The results demonstrate that for an applied power of 10-20% the expected velocities at the spit are 1.07m/s – 1.8m/s. these velocities exceed the threshold for initiation of motion (0.3-0.35 m/s). Thus, some erosion (especially of loose surface deposits) is expected to occur without any bottom or slope protection. Due to the uncertainties described in Section 5.6.2 it is unclear how much erosion may occur. Therefore, a buffer and monitoring approach is recommended, as described in Section 10.

9.3.3 Inner Harbour (-6mCD) Assessment

For the tug assisted small vessel design case the calculation results are shown in Table 9-4.

Table 9-4 Maximum current velocities for the Tug assisted Barge (Camperdown Tug) – 4°propeller angle

Location	Inner Harbour (-6mCD)
Distance of propeller axis to the dredged slope (m)	57
%-age of power applied	**10%**
Max. bed velocity (at channel bottom)	1.92 m/s (dutch) 1.79 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	0.47 m/s (dutch) 0.42 m/s (german)
%-age of power applied	**15%**
Max. bed velocity (at channel bottom)	2.19 m/s (dutch) 2.05 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	0.54 m/s (dutch) 0.48 m/s (german)
%-age of power applied	**20%**
Max. bed velocity (at channel bottom)	2.42 m/s (dutch) 2.26 m/s (german)
Max. velocity at slope of sand spit (at level of propellers)	0.59 m/s (dutch) 0.53 m/s (german)

The calculation results demonstrate that for an applied power of 10 – 20% the expected velocities at the spit for the case of a tug assisted small vessel are 0.42 – 0.59m/s. Based on these relatively low velocities, only limited erosion (especially of loose surface deposits) is expected to occur if no slope protection is provided. This could be managed with a buffer and monitoring approach, as described in Section 10.

10 Buffer and Monitoring Recommendations

The preceding sections establish that the sands of Whiteness Head are erodible and that propeller jets can, under adverse combinations of vessel, position and applied power, mobilise sediment at the dredged slope. Section 5.6 sets out why converting that susceptibility into a calculated erosion rate or scour depth is not considered reliable. Published guidance recognises this situation: PIANC Report 180 (PIANC Working Group 180, 2015) accepts two design philosophies for propeller action at port infrastructure, protecting the bed against erosion or accepting that scour may occur and managing it through monitoring, maintenance and defined intervention. The second approach is recommended for Whiteness Head.

The timescale of the process supports a monitoring-led approach. Under normal operations vessels manoeuvre at a stand-off from the slope, thrust is applied for short periods, and the jet is only intermittently directed towards any one section of slope. The erosive loading on a given part of the slope therefore accumulates over months and years of port operations rather than over individual visits, and significant scour of the slope is very unlikely to develop over a small number of routine vessel movements. Sustained direct thrust against the slope at close range, the one circumstance that could produce more rapid local scour, is avoidable through normal good practice in vessel operation. Scour at Whiteness Head is therefore expected to be a progressive and detectable process on the timescale of a practicable monitoring programme, not a sudden event.

To that effect a sensible buffer, which recognizes the potential for scouring as laid out in the preceding chapters, should be implemented along the site with an associated monitoring programme (in regular intervals and after erosion events), the details of which are to be defined by the port authority.

Local scour protection would only be required where monitoring shows that reinstatement cannot keep pace with the observed erosion. Based on this cycle of monitoring propeller scour at Whiteness Head could be managed without pre-installed scour protection.

11 Conclusions

Haskoning have notionally divided the harbour of Ardersier Port into two areas based on depth; the deeper Inner Harbour (-12.4mCD) and the shallower Inner Harbour (-6mCD). Haskoning have collated relevant information and assessed the scour potential of the proposed dredged slope on the southern bank of Whiteness Head (the sand spit adjacent to the harbour) for both areas.

For the Inner Harbour (-12.4mCD) the dominant design case for scour is an unassisted large offshore wind installation vessel. This dominates over other vessels due to the combination of a relatively large draft and a relatively large and powerful propulsion system.

For the Inner Harbour (-6mCD) the dominant design case for scour is a tug assisting a small vessel. This dominates over other vessels due to the relatively large and powerful tug propulsion system operating at a higher percentage of total installed power than other vessels.

Worst case scenario

Based on the assumed design cases the unprotected sand spit at Whiteness Head is expected to show some erosion (especially of loose surface deposits) under ship propeller scour in both the Inner Harbour (-12.4mCD) and the Inner Harbour (-6mCD). This assessment is based on the PIANC WG 180 guideline (PIANC Working Group 180, 2015) for determining propeller scour forces and the estimated erodibility of the sand spit. Sensitivity checks were also undertaken for the key underlying assumptions in the baseline scenarios. Various applied main power percentages of typical vessels (from the recommended 50% down to 10-20% applied power for berthing procedures as advised by harbourmaster) were investigated, as well as various distances between the vessel and the toe of the proposed dredged slope from 30m (baseline) up to 50m (the maximum practically available). Even in the case of the most optimistic assumptions for all the sensitivity checks combined, the calculations indicate that some erosion due to propeller scour would occur.

Due to the uncertainties described in Section 5.6.2 it is however unclear how much erosion will occur, especially of the more erosion resistant underlayers of the spit. It is therefore concluded that operational controls to maintain a minimum distance from vessels to the spit slope alone would not adequately mitigate the risk of scour, therefore a buffer and monitoring approach is proposed as discussed in Section 10.

More realistic scenario

For the more realistic scenario (based on the latest vessel and manoeuvring specifications from Ardersier Port (Scotland) Limited) with reduced power levels, angled azipods and somewhat larger distances to the spit the following has been found:

- Inner harbour (-12.4m): although the velocities for the design case at the sand spit are reduced compared to the worst case scenario, still some erosion of the spit (especially of loose surface deposits) can be expected. Again, the actual amount of erosion is difficult to assess.
- Inner harbour (-6m): only limited erosion of loose surface deposits is foreseen since the expected velocities exceed the threshold for initiation of motion by a relatively small margin.

Based on consideration of all the scenarios a buffer and monitoring approach could be successful and considered proportionate to the risks.

Buffer and Monitoring approach

As set out in Section 5.6, converting this erosion susceptibility into a reliable prediction of erosion rate or scour depth is not considered practicable. Note that the erosive loading on any one part of the slope accumulates over months and years of port operations rather than over individual vessel movements.

To that effect a sensible buffer, which recognizes the potential for scouring as laid out in the preceding chapters, should be implemented along the site with an associated monitoring programme (in regular intervals and after erosion events), the details of which are to be defined by the port authority. Local scour protection would only be required where monitoring shows that reinstatement cannot keep pace with the observed erosion.

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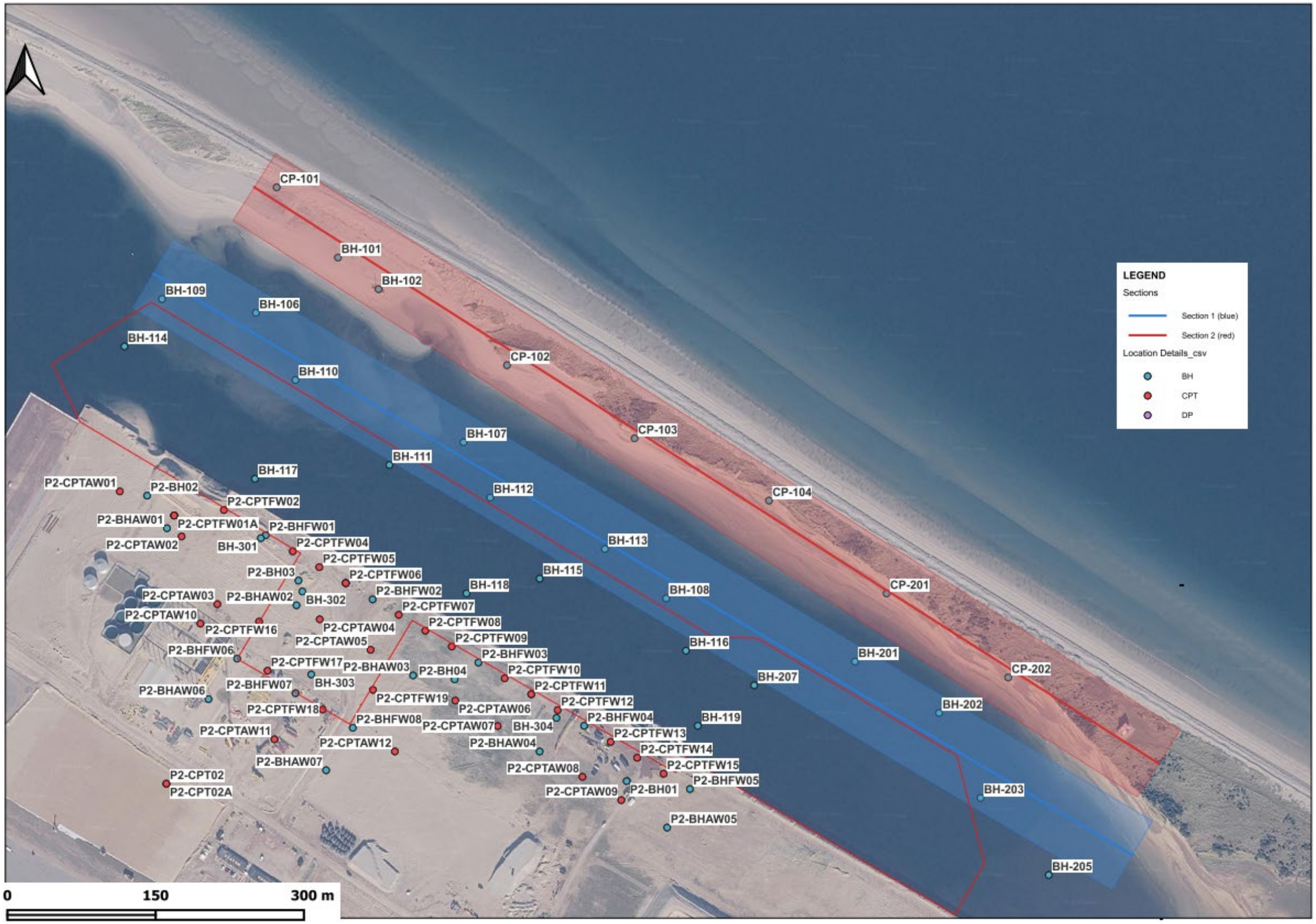
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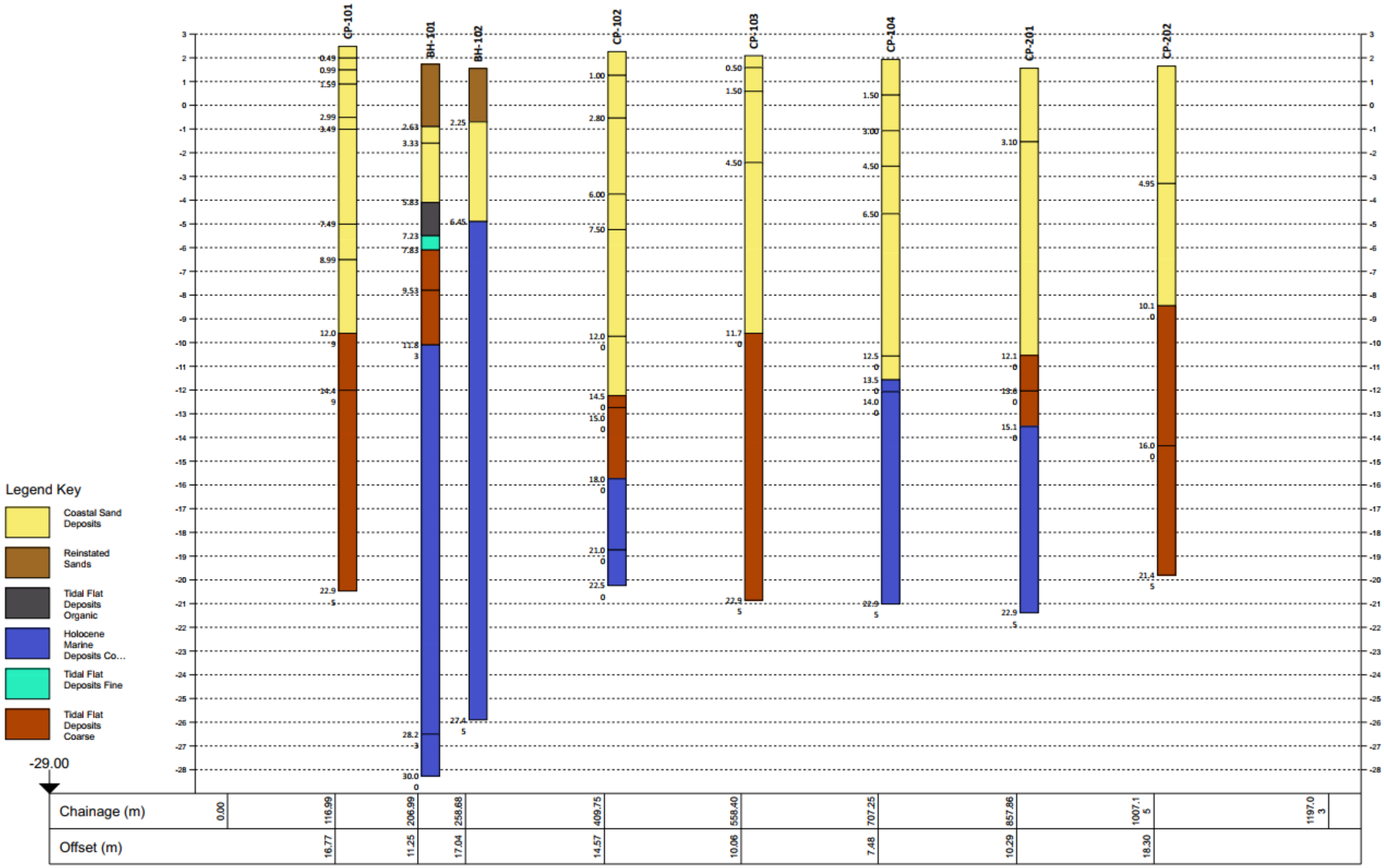
Appendix A – Geotechnical Cross-Sections and Plan

Haskoning
Enhancing Society Together

Location Plan



Section Line 1



Haskoning
Enhancing Society Together

Section Line 2

