DART+ Coastal North

ANNEX 3.2

Technical Optioneering Report: Electrification of the Northern Line between Malahide and Drogheda

SECTION B

OHLE foundation solution

ARUP

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Abbreviations

Abbreviation	Definition
AEP	Annual Exceedance Probability
CAF	Common assessment framework
CCE	Chief Civil Engineer's Department
CFA	Continuous flight auger
EIR	Eircom Limited
EPA	Environmental Protection Agency
ESB	Electricity Supply Board
GSI	Geological Survey of Ireland
MCA	Multi-criteria analysis
NIAH	National Inventory of Architectural Heritage
OHLE	Overhead line equipment
OLE	Overhead line electrification
RRV	Road rail vehicle
TSS	Train Service Specification

1 Introduction

The purpose of the report is to provide the technical input to the Preliminary Option Selection Report. This report provides the technical assessment of the foundation solutions for overhead line electrification equipment (OHLE) from option selection through to Draft Emerging Preferred Options, including a description of the options considered and how Draft Emerging Preferred Options were chosen.

The report includes:

- An introduction and description of the study;
- A summary of the option assessment approach undertaken;
- A description of the existing situation;
- The requirements;
- The foundation options available, along with comparison;
- The Draft Emerging Preferred Options.

1.1 Packages of Work

The scope of work for DART+ Coastal North covers a wide range of interventions on the Northern Line needed in order to meet the Train Service Specification (TSS) requirements. To appropriately assess options against each other, the scope of work has been split into separate work packages. Where appropriate, the works have then been further split down into sections which define the system which has been subject to the optioneering process.
This document is a section to the overarching optioneering report for the electrification of the Northern Line between Malahide and Drogheda. Please refer to Table 1-1 below for a list of the different sections which make up the electrification package of work.

Table 1-1: List of key documents associated with Electrification of the Northern Line from Malahide to Drogheda

Annex	Section	Title
Annex 3.2	A	OHLE system
	B	OHLE foundation solution
	C	OHLE foundation solution at underbridges
	D	Bridge parapet modifications
	E	OHLE Bridge Clearance works
	F	Traction Power Supply (will form part of Public Consultation 2)
	G	User worked level crossing south of Donabate
	H	Fencing and lineside safety

1.2 References

This report should be read in conjunction with the following related optioneering reports:

Table 1-2: List of key documents associated with this report

Annex	Title	Description
N/A	DART+ Coastal North Preliminary Option Selection Report	This is the main report which summarises the optioneering process and the different packages of proposed works on the DART+ Coastal North project.
N/A	DART+ Coastal North Preliminary Option Selection Report – Executive Summary	This report summarises the main Preliminary Option Selection Report.
1	Emerging Preferred Option Maps	Includes drawings for each Emerging Preferred Option, to support the Preliminary Option Selection Report.
2.1	Policy Context	This presents a detailed review of the European, National, Regional and Local policy context for the DART+ Programme and the DART+ Coastal North Project
2.2	Useful Links	Useful links to documents/websites relating to the DART+ Coastal North project.
3.1	Constraints Report	This report reviews the DART+ Coastal North constraints.
3.2	Technical Optioneering Report: Electrification of the Northern Line between Malahide and Drogheda.	The Technical Optioneering Report for the Electrification of the Northern Line between Malahide and Drogheda. The report is divided into a series of sections, as described in Table 1.
3.3	Technical Optioneering Report: Works around Drogheda MacBride Station	The Technical Optioneering Report for Works around Drogheda MacBride Station. The report addresses track and station modifications to allow for the increased number of DART services.
3.4	Technical Optioneering Report: Works around Malahide Station	The Technical Optioneering Report for Works around Malahide Station. The report addresses track modifications required to allow trains to be turned back clear of through running services.
3.5	Technical Optioneering Report: Works around Clongriffin Station	The Technical Optioneering Report for Works around Clongriffin Station. The report addresses track modifications required to allow trains to be turned back clear of through running services.

Annex	Title	Description
3.6	Technical Optioneering Report: Works around Howth Junction & Donaghmede Station	The Technical Optioneering Report for Works around Howth Junction & Donaghmede Station. The report addresses the addition of tracks to allow a higher frequency shuttle service.
3.7	Technical Optioneering Report: Howth Branch Level Crossings	The Technical Optioneering Report for the Howth Branch Level Crossings. The report addresses the impacts of all proposed increases in train frequency on existing level crossings on the Howth Branch.

1.3 Option Assessment Approach

In line with the Option Selection Process section of the Preliminary Option Selection Report, elements can be scoped out of the Multi-criteria Analysis (MCA) process based on a number of criteria, one of which is as follows:

'If the type of system to be used is solely governed by IÉ standards and specified by technical requirements, then the CAF/MCA process will not be utilised'

Since this is true for the selection of OHLE foundation solutions, the draft emerging preferred options described in this report are not subject to the MCA process and instead proposed to be based upon technical requirements as set out within this document. Options for OHLE in at bridges and structures are presented in separate options reports.

2 Existing Situation

2.1 Ground and Groundwater Conditions

A desk study has been undertaken to gather information on the general ground conditions along the route section that is to be electrified from Malahide to Drogheda. This will be used in conjunction with planned site-specific ground investigation works to inform subsequent design stages. Due to the length of the electrification work and variations in ground conations along the existing line, the route under consideration has been divided into five segments as described in the following sections.

2.1.1 Malahide (from viaduct structure) to Lusk

Geological Survey Ireland (GSI) Quaternary sediment mapping indicates that, from Malahide viaduct to Rogerstown viaduct, there is the presence of marine beach sands, Irish sea till derived from Lower Palaeozoic sandstones and shales and estuarine silts and clays. From Rogerstown to Lusk, landfill and Irish sea till derived from Lower Palaeozoic sandstones and shales were identified. Additionally, glacial lineation, alluvium deposits, drumlins and glacial meltwater channels cross the railway line.

GSI bedrock mapping shows that the site is underlain by argillaceous bioclastic limestone, shale of the Malahide formation; red coarse sandstone and conglomerate of the Donabate formation; andesite, tuff, pebbly mudstone, shale of the Portlane Volcanic formation; calcareous shale, limestone conglomerate of the Tober Colleen formation; conglomerate, shale, limestone of the Rush Conglomerate formation and finally, dark limestone and shale of the Lucan formation respectively. Moreover, synclinal and anticlinal axes and faults cross the site.

GSI depth to bedrock (Dublin County) mapping indicates bedrock depths 1 to 5m from Malahide Station and along the viaduct while historic GI indicates deeper depths of approximately 20m. Beyond this point to Lusk, bedrock depth varies significantly from 1 to 10m.

The Environmental Protection Agency (EPA) waterbodies map (2021) demonstrates that four waterbodies cross the site.

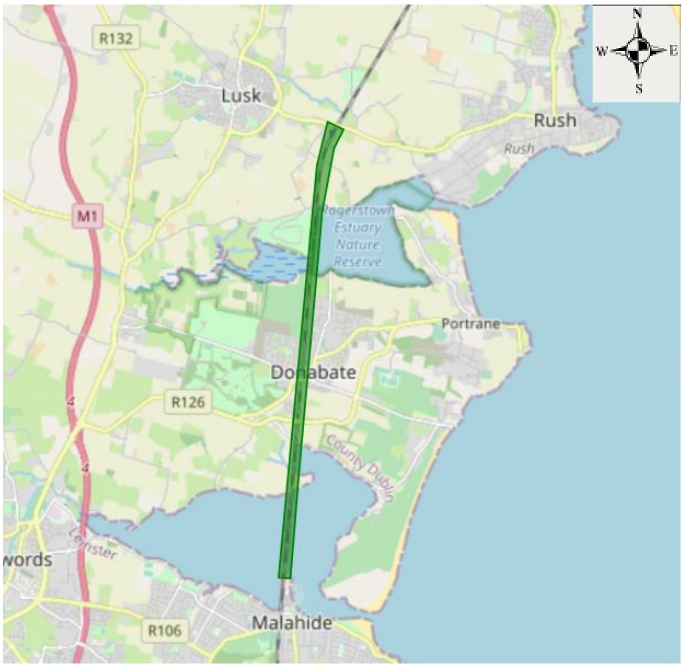

Figure 2-1: Aerial view of described ground condition section from Malahide to Lusk (Map data © OpenStreetMap contributors)

2.1.2 Lusk to Skerries

GSI Quaternary sediment mapping shows the presence of Irish sea till derived from Lower Palaeozoic sandstones and shales predominates from Rush and Lusk to Skerries with intermittent alluvium deposits and bedrock outcrops. A small portion of till derived from Namurian sandstones and shales was noted at approximately halfway along the segment. Moving towards Skerries, gravels derived from lower palaeozoic sandstones and shales are present. Moreover, glacial lineation, hummocky sand and gravel landform, lineation striae, drumlin and mega scale glacial lineation cross the line. There are also nearby glacial meltwater channels.

GSI bedrock mapping shows that the site is underlain by conglomerate, shale, limestone of the Rush Conglomerate formation; dark limestone and shale of the Lucan formation; calcarenite and calcisiltite of the Naul formation; dark micrite and calcarenite, shale of the Loughshinny formation; coarse sandstone, shale of the Balrickard formation and finally, grainstone-packstone, micrite of the Holmpatrick formation respectively. Additionally, faults and synclinal axis crossing the site were observed.

GSI depth to bedrock (Dublin County) mapping indicates bedrock depth bedrock depth varies significantly from 1 to 10m along the segment.

The EPA waterbodies map (2021) demonstrates that five waterbodies cross the site.

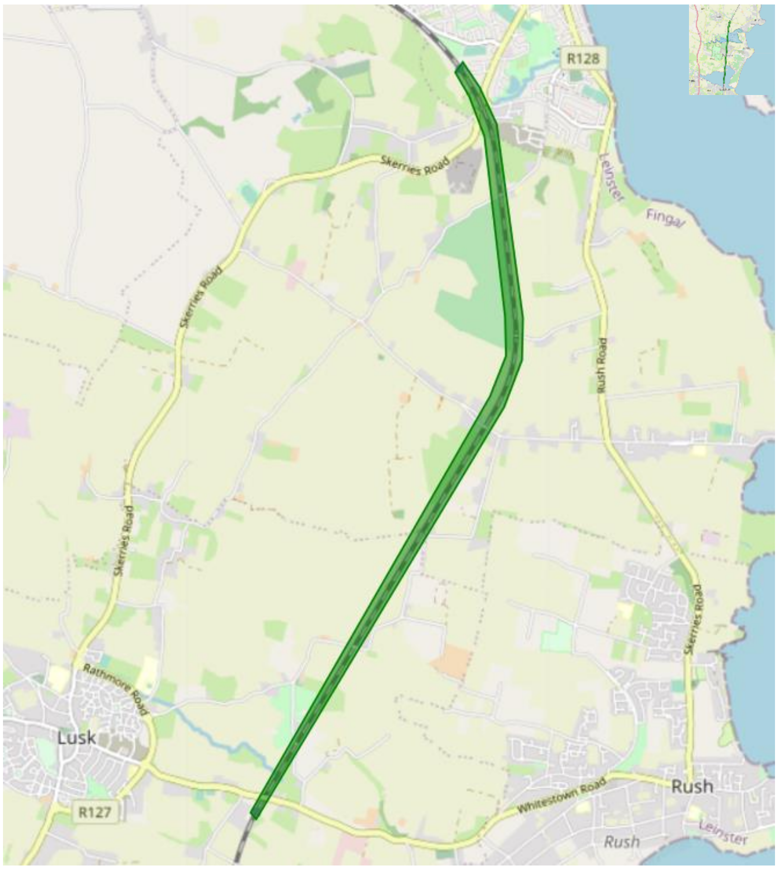

Figure 2-2: Aerial view of described ground condition section from Lusk to Skerries (Map data © OpenStreetMap contributors)

2.1.3 Skerries to Balbriggan

GSI Quaternary sediment mapping indicates the presence of gravels derived from lower palaeozoic sandstones and shales, Irish sea till derived from Lower Palaeozoic sandstones and shales with intermittent alluvium deposits. Moreover, hummocky sand and gravel landform, and glacial meltwater channels are observed.

GSI bedrock mapping shows that the site is underlain by grainstone-packstone, micrite of the Holmpatrick formation; laminated blue-grey siltstone, sandstone of the Skerries formation; pale grey limestone of the Mullaghfin formation; variably coloured mudstone of the Balbriggan formation and finally, andesite, pillow breccia, mudstone and tuff of the Belcamp formation. Faults crossing the site were identified.

GSI depth to bedrock (Dublin County) mapping shows significant variation from 1 to 10m along the segment.

The EPA waterbodies map (2021) demonstrates that two waterbodies cross the site.

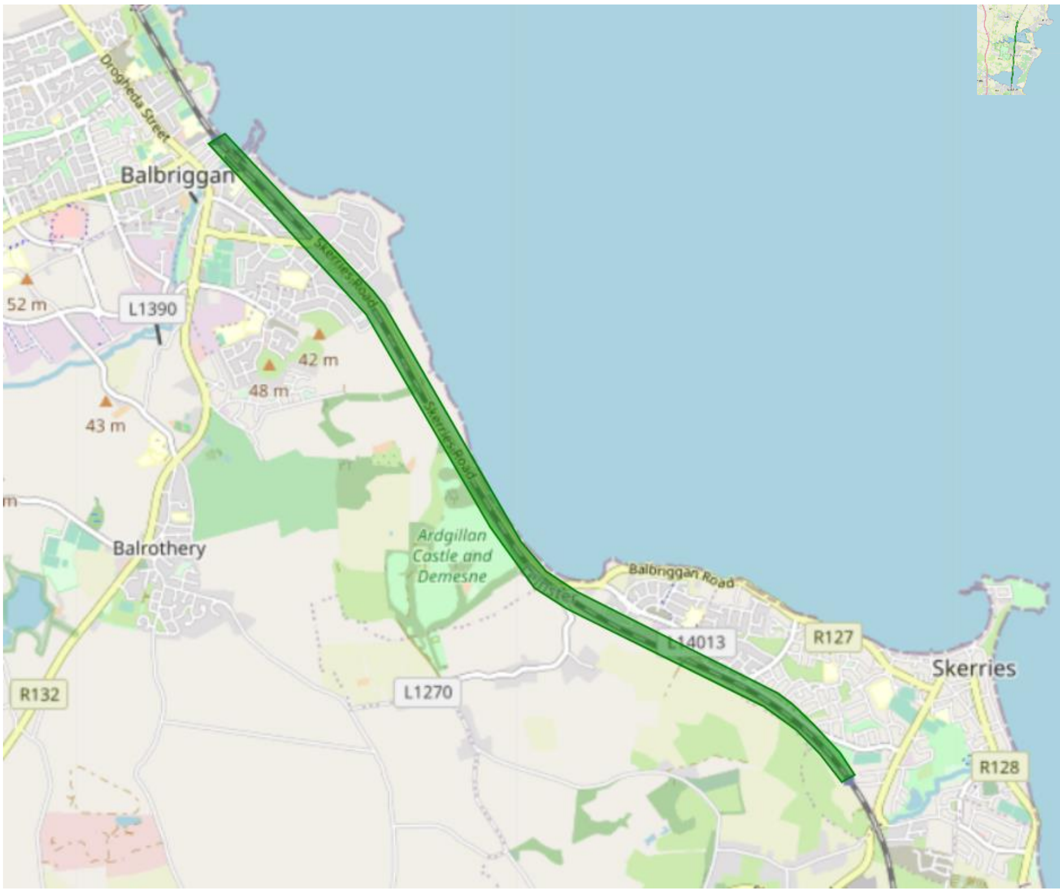

Figure 2-3: Aerial view of described ground condition section from Skerries to Balbriggan (Map data © OpenStreetMap contributors)

2.1.4 Balbriggan to Laytown

GSI Quaternary sediment mapping demonstrates the presence of Irish sea till, till and gravels derived from Lower Palaeozoic sandstones and shales, windblown sands and dunes, gravels derived from limestones with intermittent deposits of alluvium, marine beach sands and bedrock outcrops. Furthermore, deglacial landforms such as glaciofluvial terrace, meltwater channels and cut over raised peat were noted.

GSI bedrock mapping shows that the site is underlain by andesite, pillow breccia, mudstone, tuff of the Belcamp formation; greywacke sandstone & siltstone of the Denhamstown formation; thinly bedded siltstone, sandstone of the Clatterstown formation and finally, pale micritised grainstone-wackestone of the Tullyallen formation. Faults crossing the site were identified.

GSI depth to bedrock (Dublin County) mapping indicates significant variation from 0 to 10m between Balbriggan Station and 500m south of Gormanston Station.

The EPA waterbodies map (2021) demonstrates that five waterbodies cross the site.

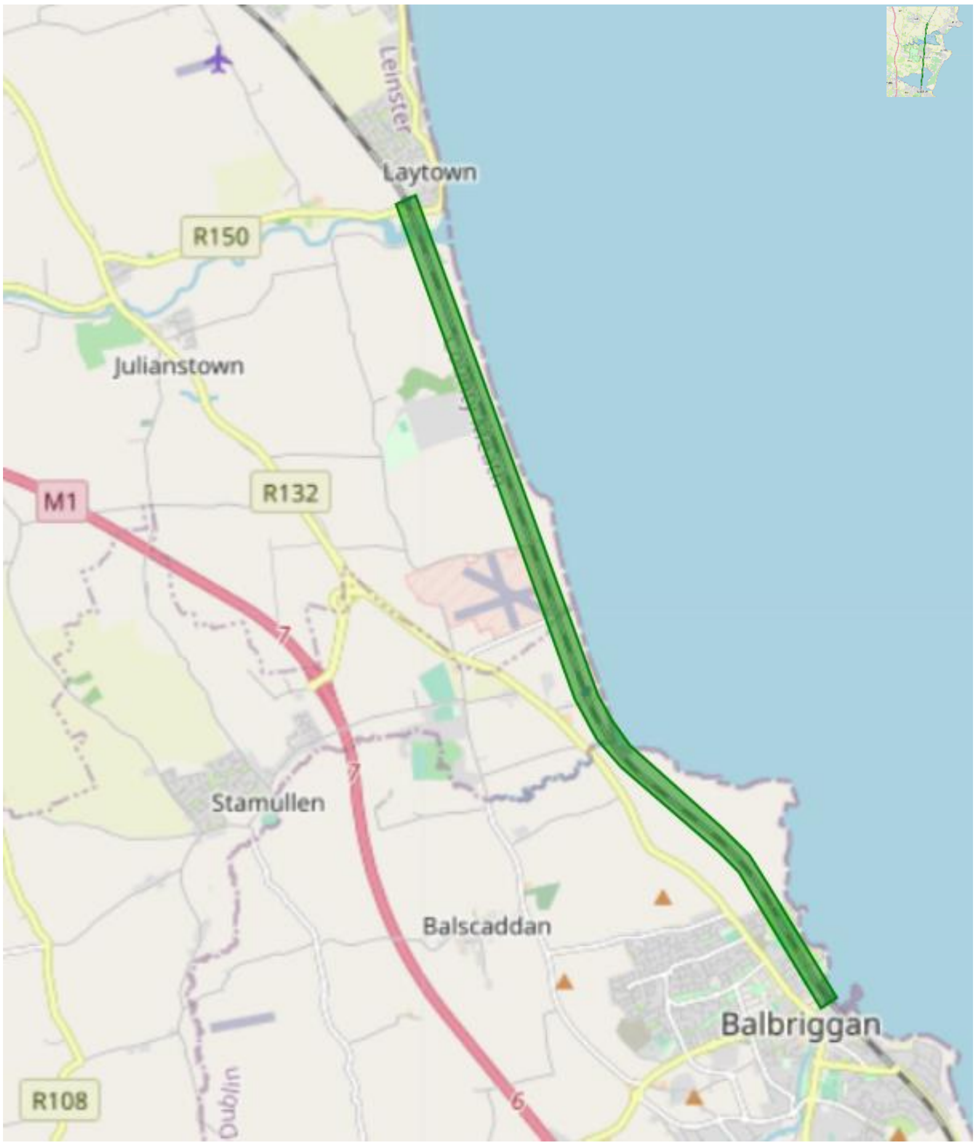

Figure 2-4: Aerial view of described ground condition section from Balbriggan to Laytown (Map data © OpenStreetMap contributors)

2.1.5 Laytown to Drogheda

GSI Quaternary sediment mapping shows the presence of gravels derived from limestones, Irish sea till derived from Lower Palaeozoic sandstones and shales and Urban (towards Drogheda MacBride Station) with intermittent deposits of alluvium and bedrock outcrops. Deglacial landforms such as glaciofluvial terrace, mega scale glacial lineation and meltwater channel were identified.

GSI bedrock mapping shows that the site is underlain by pale micritised grainstone-wackestone of the Tullyallen formation and the dark limestone and calcareous shale of the Mornington formation. A fault crossing the site near Drogheda MacBride Station was noted.

GSI depth to bedrock (Dublin County) mapping does not provide any information on the bedrock depth.

The EPA waterbodies map (2021) demonstrates that four waterbodies cross the site.

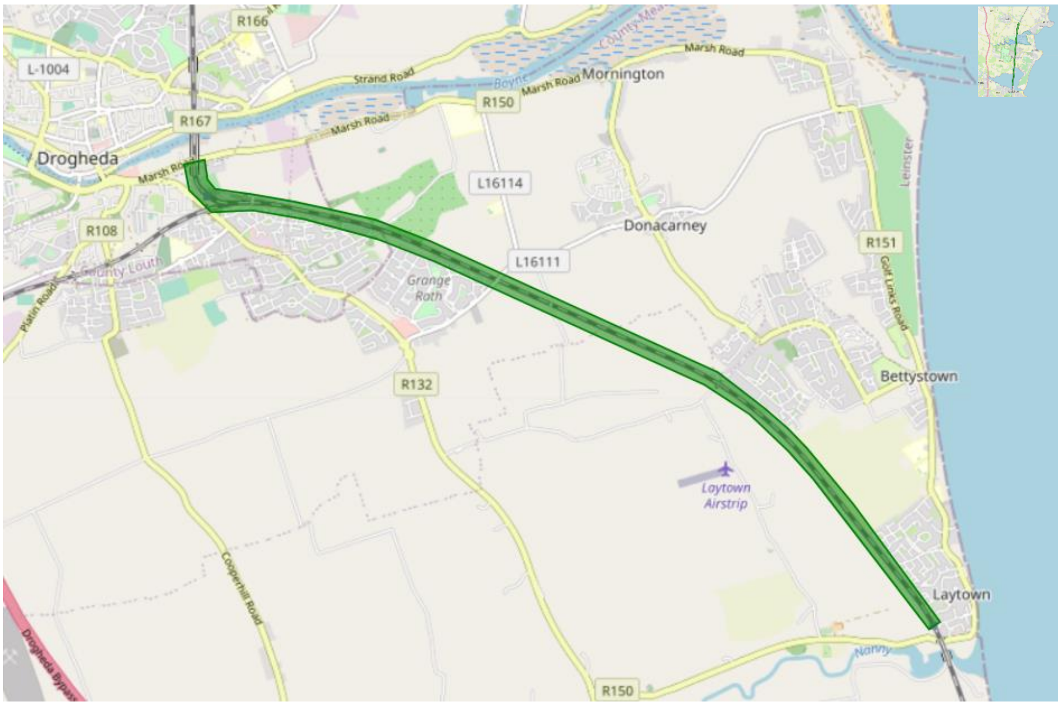

Figure 2-5: Aerial view of described ground condition section from Laytown to Drogheda (Map data © OpenStreetMap contributors)

2.1.6 General overburden stratigraphy

Limited historic ground investigation information is available for the route, and a site-specific ground investigation is proposed to inform the design. However, it is anticipated that the overburden stratigraphy comprises of made ground in urban areas with a depth of up to 5m, boulder clay deposits classified as firm to very stiff and granular deposits of medium dense to dense relative densities. Additionally, soft clay/silt and loose sand/gravel deposits have been identified along the study area.

2.2 Site History

Similar to Section 2.1, the site history overview of the line between Malahide and Drogheda has been split into five sections as described in the following sections.

2.2.1 Malahide (from viaduct structure) to Lusk

The rail viaducts over Malahide and Rogerstown estuaries were constructed in the period 1888-1913, with no evidence of prior structures. At this time, mud flats were observed at both viaducts and at Malahide, the train station was built, and historic gas works were noted. After 1913, further industrial and commercial developments occurred within the vicinity of Malahide. Latest aerial mapping indicates features such as the Rogerstown Park (formerly landfill) and Donabate distributor road along the Malahide to Lusk segment.

Numerous National Inventory of Architectural Heritage (NIAH) sites and national monuments are located within 200m and 2km from the site boundary.

2.2.2 Lusk to Skerries

Historical and aerial mapping indicate that the railway line was still under construction and the lands within the vicinity of the site were undeveloped in the period 1837-1842. Railway construction was completed in the period 1888-1913. Additionally, gravel pits with rail siding access, mill ponds, marshes and wells were spotted along the segment. Latest aerial mapping shows Roadstone Milverton Quarry (Limestones) along the segment.

Numerous NIAH sites and national monuments are located within 200m and 2km of the site boundary.

2.2.3 Skerries to Balbriggan

Historical and aerial mapping indicate that the railway line was still under construction and the lands, up to Ardgillan Demesne, were undeveloped in the period 1837-1842. Moreover, a new road from Ardgillan Demesne to Farcourt was constructed and the region at Balbriggan was significantly developed. In the period 1888-1913, railway construction, including Balbriggan Station, was finished. Gravel pits, wells and springs were observed along the segment.

Numerous NIAH sites and national monuments are located within 200m and 2km of the site boundary.

2.2.4 Balbriggan to Laytown

Historical and aerial mapping show that the railway line was under construction up to Delvin River with the surrounding lands undeveloped in the period 1837-1842. From this point up to Laytown, there is no indication of railway construction. In the period 1888-1913, considerable commercial and industrial developments were noted, including the construction of the railway line, Balbriggan and Gormanston Stations and the viaduct at Delvin River.

Numerous NIAH sites and national monuments are located within 200m and 2km of the site boundary.

2.2.5 Laytown to Drogheda

Historical and aerial mapping indicate no railway construction or land development along this segment the period 1837-1842. The railway line, Laytown and Drogheda MacBride Stations and Newtown Bridge were built in the period 1888-1913. Latest aerial mapping shows important features such as Drogheda Wastewater Treatment Plant.

No NIAH sites exist along the segment but numerous national monuments are located within 200m and 2km of the site boundary.

2.3 Utilities

There are extensive utility networks in the area surrounding the railway, particularly in the urban areas through which it passes. Service providers with network assets in the area, from whom records have been obtained, include:

- Gas Networks Ireland;
- Irish Water (Water Supply);
- Irish Water (Foul Water Sewers);
- Dublin City Council (Storm Water Sewers);
- Fingal County Council (Storm Water Sewers);
- ESB Networks – Low, Medium and High Voltage Networks;
- EirGrid
- Eir;
- BT Ireland;
- Irish Rail - Lineside cables parallel to the railway line.

Utility service records have been obtained from all providers in the area. Most services are located within the existing road network surrounding the railway, and in bridge and underpass crossings of the railway. There are also lineside services running parallel to the railway and some major utilities crossing perpendicularly under the railway. All records should be considered indicative only and must be verified prior to any intrusive works occurring.

The records indicate that there are services at track level or within the railway corridor. These include Irish Rail lineside cables, Eir telecoms cables and BT telecoms cables running parallel to the railway from Malahide to Drogheda.

There are several major utilities crossing perpendicularly under the railway between Malahide and Drogheda, as outlined below. This is a non-exhaustive list and the exact locations of existing services must be verified prior to any intrusive works occurring.

2.3.1 Malahide (from viaduct structure) to Lusk

ESB Networks / EirGrid

- The EirGrid East-West Interconnector is a 500MW HV Direct Current power cable which links the electricity grids of Ireland and Great Britain via submarine cables running between converter stations in Ireland and Wales. The cable lands north of Rush and crosses the railway to the south of Rush & Lusk Station.

2.3.2 Lusk to Skerries

Gas Networks Ireland

- There is a 750mm diameter 75 bar high pressure gasmain crossing under the railway approximately 2.3km to the north of Rush & Lusk Station. This forms part of GNI Interconnector 1 and connects to the Loughshinny Reception Terminal before continuing under the Irish Sea to Scotland.

ESB Networks

- There is a HV electrical cable crossing under the railway approximately 2.1km to the north of Rush & Lusk Station.

2.3.3 Skerries to Balbriggan

ESB Networks

- There is a HV electrical cable crossing under the railway approximately 400m north of Skerries Station, close to Selskar Avenue.

Irish Water (Water & Wastewater Networks)

- There is a 180mm diameter watermain crossing under the railway approximately 2km south of Balbriggan Station.
- There is a 600mm diameter foul sewer rising main crossing under the railway approximately 1.7km south of Balbriggan Station. This pipe crosses under the railway and the R127 Skerries Road and continues south towards Skerries.
- There is a 350mm diameter foul sewer rising crossing under the railway approximately 1.7km south of Balbriggan Station. This pipe crosses under the railway and the R127 Skerries Road and continues north towards Balbriggan.
- There is a 450mm diameter foul sewer crossing under the railway approximately 550m south of Balbriggan Station at Fancourt Road.
- There is a 225mm diameter foul sewer crossing under the railway approximately 360m south of Balbriggan Station.
- There is a 100mm diameter watermain crossing under the railway approximately 240m south of Balbriggan Station, connecting from Church Street to Seapoint Lane.

2.3.4 Balbriggan to Laytown

Gas Networks Ireland

- There is a 750mm diameter 145 bar high pressure gasmain crossing under the railway approximately 600mm to the north of Gormanston Station. This forms part of GNI Interconnector 2 and connects to the Gormanston

Reception Terminal to the west of the railway and continues onwards to Scotland to the east.

2.3.5 Laytown to Drogheda

Gas Networks Ireland

- There is a 250mm diameter 70 bar High Pressure gasmain crossing under the railway. This is approximately 2.3km south of Drogheda Station at Park Ridge

Irish Water (Wastewater Network)

- There is a 375mm diameter foul sewer crossing under the railway. This is approximately 950mm south of Drogheda Station at Chestnut Grove.

3 Requirements

The chosen OHLE system, as described in Section A of Annex 3.2, requires regular supporting masts in open route. The spacing of such structures in open route for design purposes is typically up to 63m for straight track, with reductions based upon radius down to 20m. Foundations will be required at each mast location (aside from those fixed to existing structures - refer to Section C of Annex 3.2 - and shall be designed to resist the vertical and transverse loads from the system. At any given location, the foundation solution selected must be suitable for the ground conditions which, as described in previous sections, vary significantly along the route. It is likely that low headroom and micro piling methods will be required at station locations.

Cast in-situ concrete bored methods will involve the generation of pile arisings, which will need to be disposed of offsite in accordance with waste regulations.

The design will be in accordance with the DART+ Electricity Functional Specifications System-Wide MAY-MDC-ELE-DART-SP-E-0002. The design will consider section 10 of IÉ standard CCE-TMS-410 for OHLE support structures. The standards provided within this section do not constitute an exhaustive list and all relevant IÉ standards will be adopted during the design process, as relevant.

Fundamental to installing OHLE foundations in the rail environment is to reliably install solutions within gaps in train service (overnight or during planned closures).

4 Foundation Options

A preliminary assessment of the OHLE foundation options has been undertaken. This has considered various foundation solutions based on the geological conditions present along the line. The ground conditions are highly variable and there is very limited current ground investigation along much of the route (see Section 2.1). The type, nature and depth to competent bearing strata is the key driver for selecting foundation type.

There is limited recent Irish piling industry experience of installation, using track mounted equipment, of foundations for railway electrification, with the last known projects the electrification from Bray to Greystones in the late 1990s and upgrade works at Clongriffin station circa 2009-2010. The existing foundations on the current DART line (Malahide/Howth to Greystones) are understood to include a mixture of concrete pads on piles, ground bearing pad foundations, OHLE attached to existing structures or screw pile foundations (limited number).

A summary of the advantages and disadvantages of different foundation solutions is presented in Table 4-1.

Table 4-1: Foundation options and their relevant advantages/disadvantages

Type	Description	Advantages	Disadvantages
Bored Piles	Reinforced concrete bored piles – installed using an auger tool (see Figure 5-2, right-hand images)	• Can be of variable length and designed to suit as found ground conditions • Reduced vibration and noise cf. driven piles • Larger pile diameters and thus capacity cf. driven piles	• Penetration into hard rock likely an issue • Slower construction than driven • Produces spoil for removal off-site. • Would need permanent casing if constructed within open track ballast (e.g., within an embankment). • Casing required in soft alluvium or granular soil types. • Road-Rail Vehicle mounted rigs will have reduced crowd force (downward) limiting achievable depths and resulting in potential shallow refusals.
	Reinforced concrete bored piles – installed using a percussive down the hole hammer (DTH) (see Figure 5-2, left-hand image)	• Shallow obstructions and rock not an issue • Can be of variable length and designed to suit as found ground conditions • Reduced vibration and noise cf. driven piles • Larger pile diameters and thus capacity cf. driven piles	• Slower construction than driven • Produces spoil for removal off-site. • Would need permanent casing if constructed within open track ballast (e.g., within an embankment) • Casing required in soft alluvium or granular soil types.
	Drilled permanent circular hollow section steel piles – installed using a Van Elle Elemex[1],	• Suitable in most ground conditions particularly where shallow obstructions and rock exist • Reduced vibration and noise cf. driven piles	• Noise and dust in built-up areas cf. RC bored pile solution • Requires large compressor to support works.

[1] Esser J and Lethbridge R (2020); Great Western railway electrification, UK: foundations for overhead line equipment. *Proceedings of the Institution of Civil Engineers – Civil Engineering* 173(6): 47–53.

	SSAB RD pile or equivalent systems (see Figure 5-3)	• Larger pile diameters and thus capacity cf. driven piles	• Limited pile lengths and limited scope to alter pile length during construction due to unforeseen ground conditions on site. • Requires greater prefabrication efforts. • Reduction in shaft friction compared to other pile solutions due to annulus formed by the oversized cutting ring on the steel casing toe. Additional in situ reinforced concrete may be required.
Driven Piles	Driven steel or concrete piles (see Figure 5-6)	• Speed – no in situ concrete or rebar required • No spoil generation	• Refusal leading to lateral stability design requirements not being met • Noise in built-up areas • Vibration close to existing infrastructure • Not suitable in shallow rock and obstructions.
Screw Piles	Central steel shaft with one or more helix installed by rotation (see Figure 5-7)	• Quick installation • Equipment can be mounted on RRVs (Road Rail Vehicles) • Suitable in overburden soils. • Limited spoil produced. • Previously used on IÉ projects (Clongriffin, Grand Canal)	• Pile groups likely required • Not suitable in shallow rock and obstructions.
Micro Piles	Small diameter bored piles (see Figure 5-5)	• Uses low headroom construction equipment. • Small diameter and quick to install • Shallow obstructions and rock not an issue	• A group of piles will be required, thus more time consuming • Needs a bigger pile cap

Shallow Foundations	Ground Bearing - cast in situ	• Simple construction method	• More instructive and thus time consuming to construct • Excavation and backfilling required. • Notable construction material delivery required to the location • Restricted by excavation depths and proximity to existing track infrastructure. • Larger footprints compared to other solutions • Not suitable for embankments
	Ground Bearing – precast (see Figure 5-4)	• Precast element arrives to site and is placed onto formation.	• Excavation and backfilling required. • Restricted by excavation depths and proximity to existing track infrastructure. • Larger footprints compared to other solutions • Not suitable for embankments

5 Summary and Conclusions

Based upon the previous section, the draft emerging preferred foundation options for the OHLE foundations are:

1. Rotary bored pile solutions:

   a. *Percussive drilling methods:*

   Rotary bored piling methods allow for the construction of large diameter reinforced cast in situ concrete piles in various ground conditions, both overburden and rock stratigraphy. The primary advantage of this method is ability of the equipment (see Figure 5-2) to bore through obstructions and create rock sockets. Their disadvantage is that penetration into hard rock may be an issue due to the capacity of the RRV piling equipment. In addition, installation of bored piles through significant depths of embankment may require a permanent steel tube to allow construction of the pile.

   b. *Drilled permanent circular hollow section steel piles*

   The use of drilled permanent circular hollow section steel piles offers a bored piling method where shallow refusal due to rock may occur. Consideration for the reduction in shaft capacity due to the annulus between the casing and the surrounding soil is required and may result in the need for reinforced concrete elements below the toe of the steel section. Details of this method are set out in Esser & Lethbridge (2020)[2].

2. Shallow foundations:

   This solution is best suited in areas where the track geometry and topography are favourable and the ground conditions are identified to be suitable at shallow depths, e.g., shallow competent rock. These comprise reinforced concrete ground bearing structures, constructed at the location or precast off-site (see Figure 5-1 and Figure 5-4). Construction processes are considered standard, however their larger footprint, impact of excavations adjacent to the rail line and material import/export need to be considered.

3. Micro piles:

   Small diameter piles (<300mm) may be required within areas of low headroom or constrained access. These may require a number of piles with a reinforced concrete pile cap on which the OHLE mast is fixed (see Figure 5-1 and Figure 5-5).

A significant risk identified for the project is the potential shallow refusal of piled foundation options and the consequent delay to train operations. As such, driven

[2] Esser J and Lethbridge R (2020); Great Western railway electrification, UK: foundations for overhead line equipment. *Proceedings of the Institution of Civil Engineers – Civil Engineering* 173(6): 47–53.

(see Figure 5-6) and screw piles (see Figure 5-7) are considered high risk solutions due their potential to not achieve the required design toe level (i.e., shallow refusal); although they may provide a fast and economical solution in some ground conditions, their use is considered limited in the overall study area. The project's site-specific ground investigation aims to investigate these conditions such that shallow refusal risks can be mitigated during preliminary design.

It is likely that the majority of OHLE foundation solutions will be concrete bored piles or drilled permanent circular hollow section steel piles. The key to accommodating variable ground conditions during construction is the ability to both alter the pile length and reinforcement cage length easily on site. Having the appropriate rail mounted equipment is fundamental for the success of this approach.

The well-established approach by Irish piling contractors for drilling through Irish hard rocks is achieved by using high powered modern steel (e.g., caterpillar) track mounted equipment. Given the limited recent industry piling experience in Ireland of installing piles on rail mounted vehicles, piling equipment will need to be altered to a rail track mounted system while maintaining the ability to penetrate through hard rocks. Early contractor involvement culminating in an advance construction trial is recommended. This should be considered across the whole DART + programme, particularly for those projects that will start in advance of DART+ Coastal.

The choice of foundation option will be considered during detailed design based upon the project specific ground investigation results and the finalised functional requirements of the OHLE system.

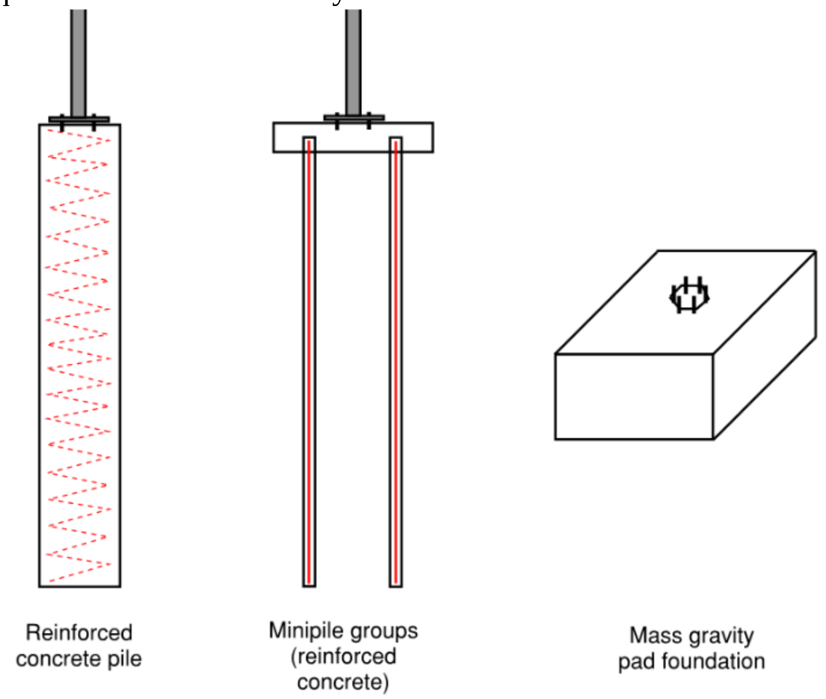

Figure 5-1: Potential OHLE foundation solution options (source Arup)

Figure 5-2: Example of a rail mounted rotary bored piling system; *left:* auger type drilling equipment, *right:* percussive down the hole hammer drilling equipment (source Arup)

Figure 5-3: Drilled permanent steel pile OHLE foundation solution option (source Van Elle)

Figure 5-4: Precast ground bearing pad foundation and micro-pile solution (source Van Elle OHLE SmartBase)

Figure 5-5: Mini-pile foundation solution; *top;* three-pile group following piling works and placement of concrete blinding, and *bottom;* foundation following construction of the reinforced concrete pile cap. (source Arup)

Figure 5-6: Driven (circular hollow section) steel pile installation (source Van Elle)

Figure 5-7: Screw pile foundations for OHLE; *top;* screw pile installation (source Van Elle), and *bottom*; four pile group screw pile foundation (source IÉ)