METROLINK

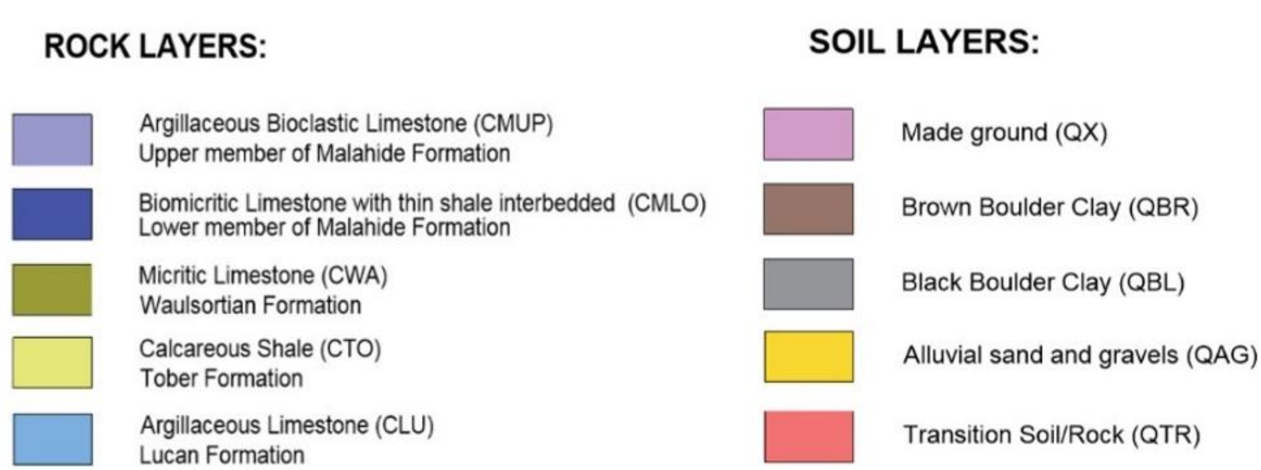
Integrated Transport. Integrated Life.

A5.13 Tunnelling

Contents

List of Abbreviations

Acronym	Meaning
DANP	Dublin Airport North Portal
DASP	Dublin Airport South Portal
D-Walls	Diaphragm Walls
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EPB	Earth Pressure Balance
HGV	Heavy Goods Vehicles
M&E	Mechanical & Electrical
OHLE	Overhead Line Equipment
SCL	Sprayed Concrete Lining
STMP	Scheme Traffic Management Plan
TBM	Tunnel Boring Machine
T&C	Testing and Commissioning
Geological Abbreviations	



1. Introduction

As detailed in Chapter 4 (Description of the MetroLink), the alignment through Dublin Airport and the City is achieved through two bored tunnel sections. It is proposed to construct two single-bore tunnels using a Tunnel Boring Machine (TBM). Each section of tunnel will have a 9.2m outside diameter and will contain both northbound and southbound rail lines within the same tunnel. There are two main TBM tunnels, which are described in this report:

- The Airport Tunnel: running south from Dublin Airport North Portal (DANP) under Dublin Airport and surfacing south of the airport at Dublin Airport South Portal (DASP). (See references to 'Drive one' in this report); and
- The City Tunnel: running south from Northwood Portal and terminating underground south of Charlemont Station. (See references to 'Drive two' in this report).

In addition, there are two much shorter tunnels that are currently planned to be driven by TBM or Sprayed Concrete Lining (SCL) techniques. These are the intervention tunnels, required to provide emergency access and egress from the main tunnel.

The City Tunnel will extend 320m south of Charlemont station. A parallel evacuation and ventilation tunnel is required from the end of the City Tunnel back to Charlemont Station to support emergency evacuation of maintenance staff and ventilation for the tunnel section south of Charlemont.

An intervention tunnel is required to provide emergency access and egress from the Airport Tunnel under Dublin Airport and emerge to the south and outside the airport grounds, as the length of the tunnel south from the Dublin Airport Tunnel exceeds 1km and it is not safe for railway passengers to be evacuated landside of the airport runways.

The openings at the end of the tunnel are referred to as portals. They are concrete and steel structures designed to provide the commencement or termination of a tunnelled section of route and provide a transition to adjacent lengths of the route which may be in retained structures or at the surface.

There are three proposed portals, which are:

- DANP;
- DASP; and
- Northwood Portal. This portal will be used during the Construction Phase to provide a launching position for the TBM. Following completion of this phase, it will be connected to Northwood Station.

There will be no portal at the southern end of the proposed Project, as the southern termination and turnback would be underground.

This report describes the tunnel alignments, associated construction areas and operation of the TBM.

2. Location

The construction of the tunnels will require the use of a number of construction sites. The main sites required are listed in Table 2-1.

Table 2-1 Schedule of Sites Associated with the Tunnel Works

Site	Launch and drive TBM	Receive TBM	TBM burial site	Tunnel clean out support	First stage concrete support	Track and MEP installation support
1. Airport South (Old Airport Road) Portal	✓			✓	✓	
2. Airport North (Naul Road) Portal		✓				
3. Northwood Portal	✓			✓	✓	
4. South of Charlemont			✓			
5. Griffith Park				✓	✓	
6. Estuary						✓
7. Dardistown Depot						✓

Please refer to the following specific sections of this report for further details on the individual site layouts.

2.1 Tunnels Site 1: Dublin Airport South Portal

2.1.1 Site Area

The Central Section TBM is to be launched on its drive (beneath the airport) from a tunnel portal constructed just to the South of Old Airport Road – refer to Diagram 2.1.

Diagram 2.1: Dublin Airport South Portal Location

2.1.2 Site Access and Egress

Separate site entrances and exits to the compound will be provided. This is the preferred option wherever possible as it encourages:

- A one-way route through site with no reversing;
- Segregation of work traffic from private cars; and
- Segregation of vehicles from pedestrians.

The proposed locations of the site entrance and exit are shown below on Diagram 2.2.

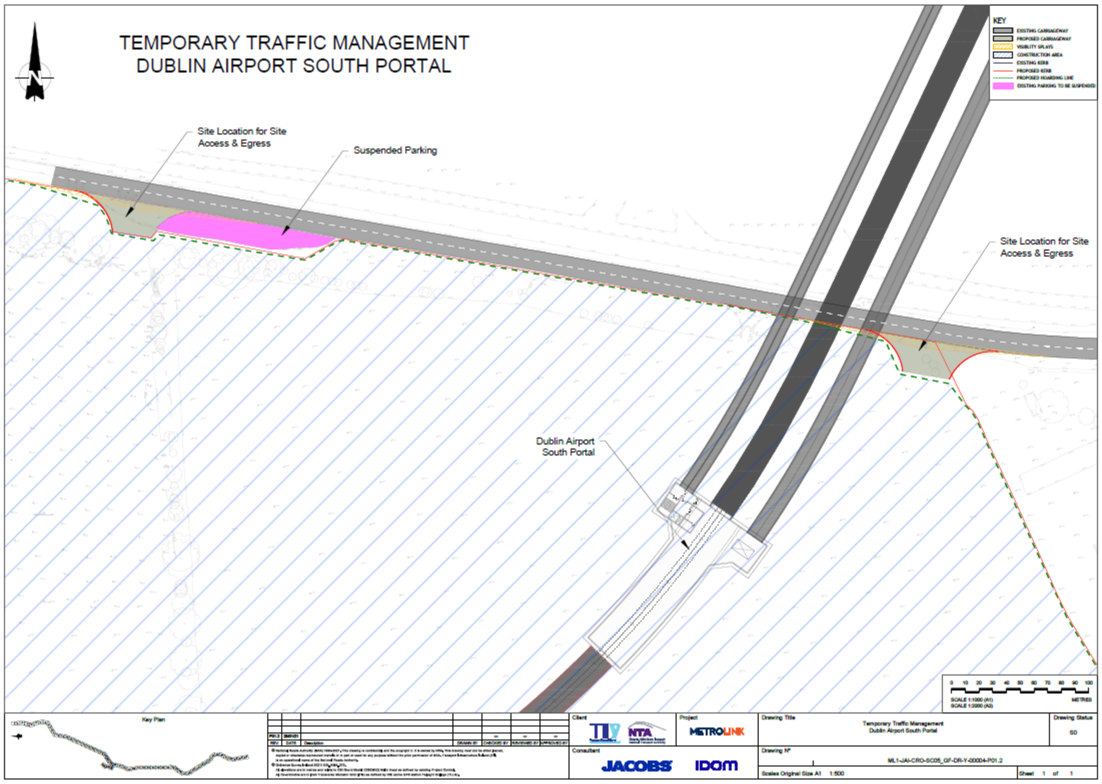
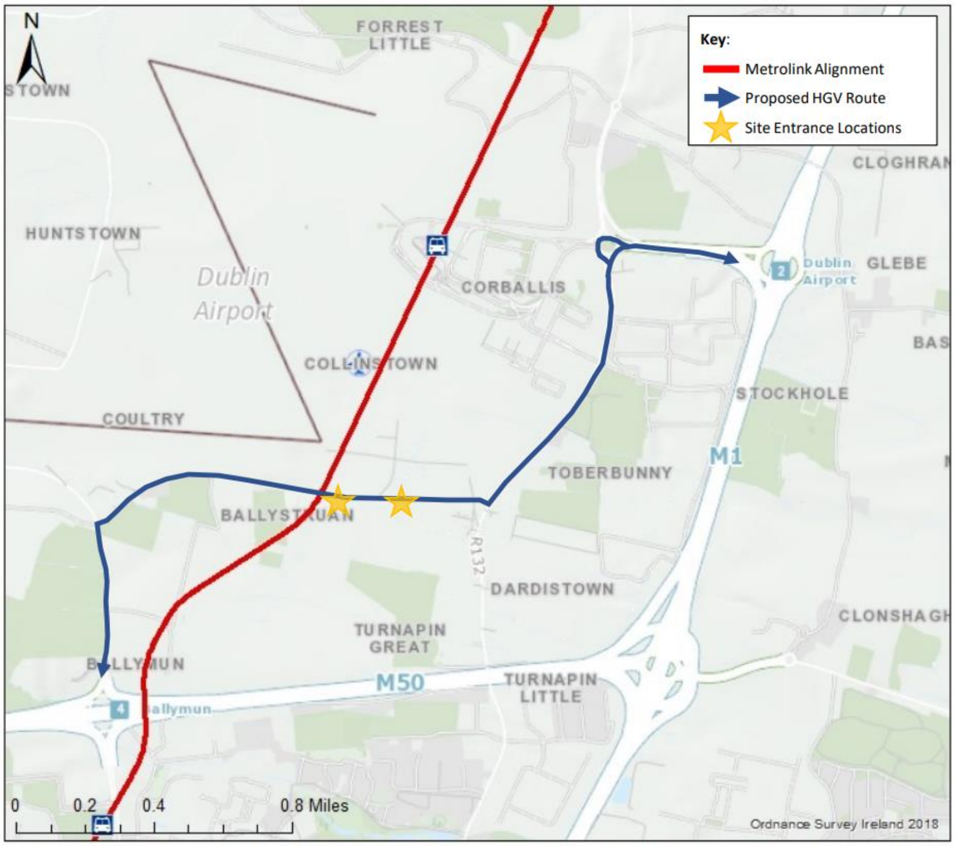


Diagram 2.2: Dublin Airport South Portal: Proposed Portal and Site Access/Egress

Vehicles delivering to site are expected to approach via the M50 and turn north onto the R108 Ballymun Road, before taking a right-turn into Old Airport Road, followed by a further right-turn into the site. The total distance is only 2km.

Traffic leaving site would turn left onto Old Airport Road and then left again onto the R108 to the M50.

A separate pedestrian entrance is proposed off Ballymun Road for those working on or visiting site who arrive on foot or by public transport. The proposed HGV route to and from site is shown in Diagram 2.3. Further traffic arrangements are detailed in the Scheme Traffic Management Plan (STMP) in Appendix A9.4 in Volume 5 of this EIAR and assessed in Chapter 9 (Traffic & Transport).



©Ordnance Survey Ireland 2021/ OSi_NMA_273. All elevations are in metres and relate to OSi Geoid Model (OSGM02) Malin Head as defined by existing Project Control. All Co-ordinates are in Irish Transverse Mercator Grid (ITM) as defined by OSi active GPS station Tallaght College (TLLG).

Diagram 2.3: Proposed HGV Route to and from Site

2.1.3 Portal Construction

The DASP will be constructed using Cut and Cover techniques – please refer to Chapter 5 (MetroLink Construction Phase) of this EIAR for further information on this construction technique. The portal will be approximately 70m in length.

2.1.4 Tunnelling Support

During tunnelling, the site must include:

- A slurry treatment plant for separating the excavated material from the TBM (when in 'slurry' mode) from the transfer slurry, which is then stored and re-used. (Refer to Section 4.4.4 for details of the TBM slurry mode);
- Conveyors for the transfer of excavated material from the TBM (when in 'EPB' mode (Earth Pressure Balance)) from the portal to the storage area. (Refer to Section 4.4.3 for details of the TBM EPB mode);
- Storage for excavated material and an area for loading this into road vehicles (including a holding area for the tipper-type trucks to wait);
- Craneage to lift plant and material in and out of the portal structure (these are likely to be gantry cranes, but mobile and crawler cranes will also be required at times);

- A tunnel grout plant to store and mix the grout used to fil the annulus around the tunnel rings;
- Large storage areas (secure, covered and open (with bunds as appropriate)) for efficient deliveries and to minimise the risk of delay from material supply;
- Workshops and repair areas;
- A substantial HV power supply (approx. 7MVA), switch, sub-station, transformers and electrical distribution;
- Tunnel ventilation;
- Large tanks in which the TBM cooling water cools down prior to going back into the TBM;
- Rainwater collection from roofs and storage for recycling;
- Site run-off collection and water treatment tanks for this and water pumped from the tunnel;
- A wheel wash over which all HGVs leaving site must pass;
- A large office and welfare complex; and
- A small carpark for staff, workforce and visitors. The use of public transport should be encouraged by the provision of a minibus pick-up from bus or rail stops.

An indictive site layout for the DASP compound during tunnelling is included as Diagram 2.4 below.

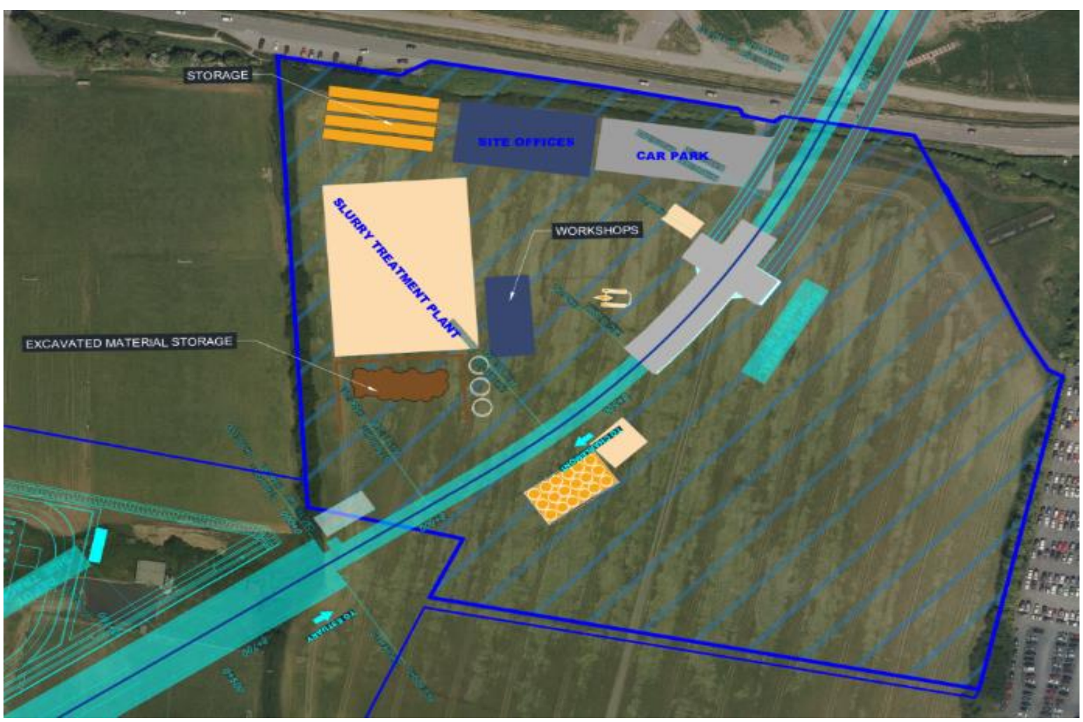


Diagram 2.4: Dublin Airport South Portal: Indicative Site Layout during TBM Tunnelling

2.1.5 Finishing Works

Following completion of the TBM running tunnel from this site, the following will be required:

- Drive the two shorter tunnels (Evacuation and Ventilation);
- Completion of the cut and cover structure and backfill over;
- Construction of the permanent ventilation and escape structure; and
- Installation of the drainage and other mechanical and electrical (M&E) installations.

2.2 Tunnels Site 2: Airport North Portal

2.2.1 Site Area

The Dublin Airport North Portal (DANP) site will be used:

- By the Central Section Contractor to construct the portal and to remove the TBM; and
- By the Northern Section Contractor to supply work areas as far as the first crossing of the R132, a section which is largely at grade, but also includes the crossover and turn-back facility.

Consequently, the site can occupy a smaller area than the TBM drive sites.

The DANP main construction compound is located immediately north of the Airport perimeter fence, which runs along Naul Road (see Diagram 2.5).

In this location the ground rises rapidly and a relatively short portal (60m) is sufficient to achieve the necessary cover for a break-out.

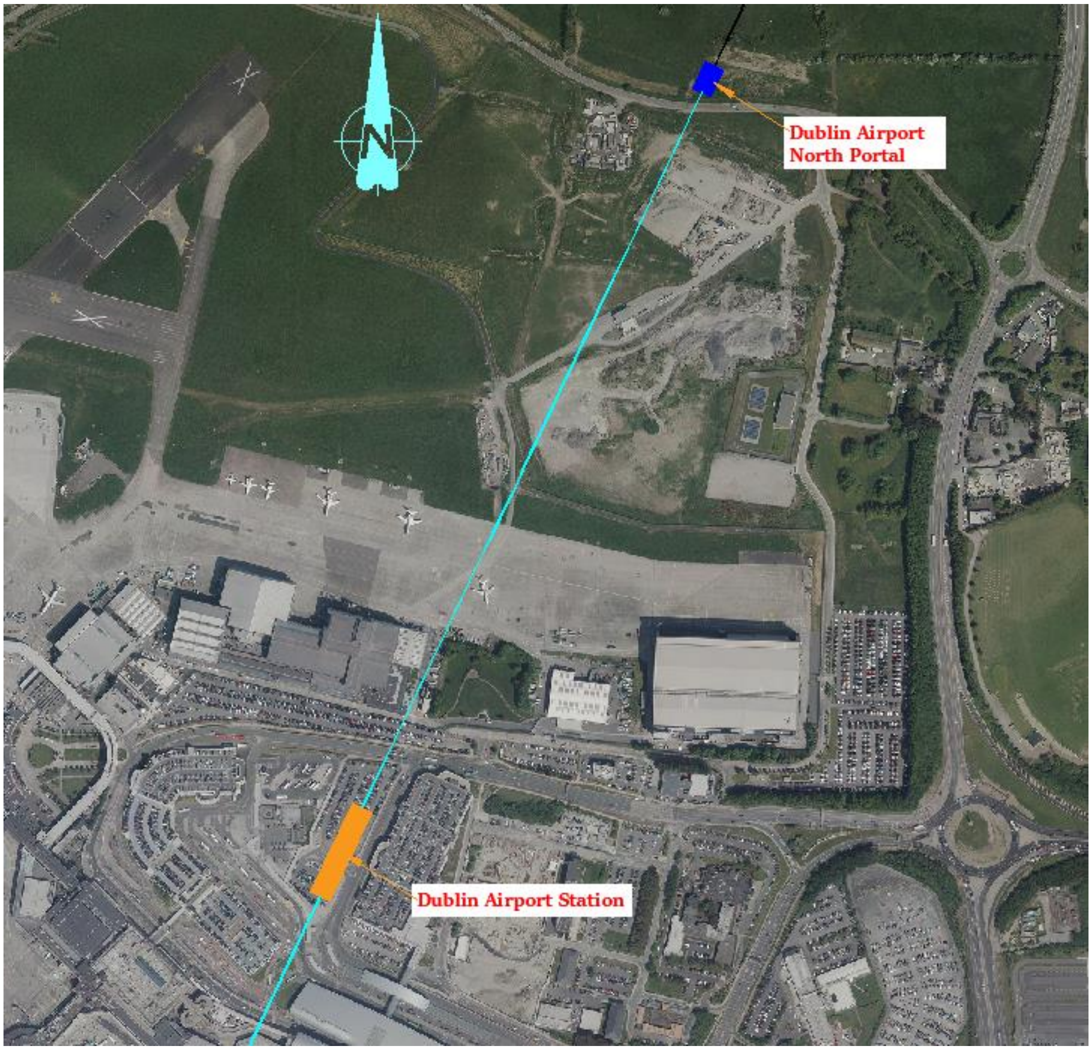


Diagram 2.5: Dublin Airport North Portal Location

2.2.2 Access and egress

HGVs travelling to the DANP site will approach from the M1, turn west on to the Airport approach road, then at the next roundabout, turn right (north) on to the R132. At the next roundabout, turn left onto Naul Road.

HGVs leaving site will reverse the above directions to reach the M1, a distance of just over 1.5km.

2.2.3 Portal Construction

The DANP will be constructed using Cut and Cover techniques. Please refer to Chapter 5 (MetroLink Construction Phase) of this EIAR for further information on these construction techniques.

2.2.4 TBM Dismantling

The Airport Tunnel TBM will break through into DANP, be dismantled and then transported off site.

Pieces will be split, lifted and taken off-site in sections. Piece sizes will be as large as possible to minimise the works on site but must be suitable for transport to the final destination.

Sections must be thoroughly cleaned of grease, oil and dirt before loading on to transport, with these works carried out in a purpose built 'cleaning bay' from which drainage water will be collected and passed through a silt buster treatment plant (or similar) and an oil interceptor.

2.3 Tunnels Site 3: Northwood Portal

The second TBM drive will be from the Northwood Portal.

The proposed Northwood Station is located adjacent to and encompasses R108 Ballymun Road. The construction site will include land on both sides of R108 Ballymun Road and adjacent to St Margaret's Road. There will also be a station logistics site located north of St Margaret's Road. The portal construction works and the station works from the west of the R108 Ballymun Road will be supported from the Northwood Station and Portal Main Construction Compound. This area is located in an open, greenfield site, away from residential and commercial development.

The construction site footprint will change throughout the construction timeframe but will generally consist of two main sites. The East Site is located east of R108 Ballymun Road and the West Site is located to the west of R108 Ballymun Road and south of St Margaret's Road.

The main construction works will require the realignment of R108 Ballymun Road throughout the majority of the construction timeframe.

The proposed traffic management for the Northwood Station involves the realignment of the R108 and alteration to junctions on R108 / Northwood Avenue and R108 / St Margaret's Road. There will also be a new signalised junction on St Margaret's Road, approximately 200 meters west of the R108/ St Margaret's Road junction, which will facilitate site access. New pedestrian provision and segregated cycle facilities will be provided along the proposed new road. As part of the temporary traffic management changes, Balbutchers Lane (R104) will also be redesigned to better accommodate pedestrian and cyclist movements.

The site access points for both the east and west sites will be on the R108 Ballymun Road/ St Margaret's Road signalised junction. The site exit for the west site will be off St Margaret's Road.

The temporary traffic management for Northwood Station construction site has been developed as a hybrid option of two previously considered options and represents the most effective choice to maintain capacity as best as possible and to minimise any potential impact on the strategic road network. A Construction Phase Traffic Impact Assessment has been undertaken at Northwood Station and is presented in the STMP in Appendix A9.4 in Volume 5 of this EIAR.

Due to this site being required for the City Tunnel launch site, the site is of sufficient size to receive delivery vehicles within the hoardings to minimise the impact of vehicles idling and causing congestion on the local roads during offloading.

Northwood Station is to be constructed beneath the R108, which will require the closure of lanes of the road, with traffic diversions in place. This means that the completion of the station is relatively late and the TBM would need to wait before launching from the station. In order to allow the TBM to arrive direct from the manufacturer and to launch straight away, a short additional open-cut box structure is proposed to the southwest of the station.

The site is 30,000 to 35,000m2, which allows for sufficient material stockpiles to ensure efficient operation. This area will house the site offices, segment storage area, slurry treatment plant, gantry cranes, power supply, workshops, grout batching plant and car park.

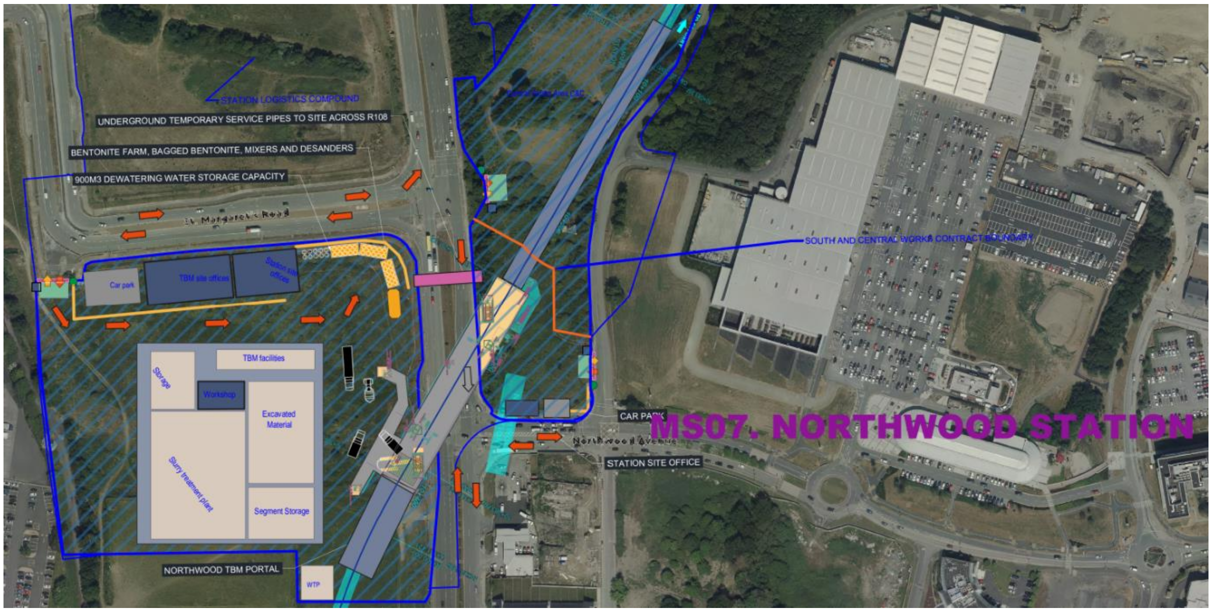


Diagram 2.6: The Proposed Northwood Portal Site

2.3.1 Portal Construction

The Northwood Portal consists of a cut and cover structure which will be constructed ‘bottom up’ in order to achieve the earliest possible TBM launch date.

The Northwood Portal structure will be constructed concurrently with the Northwood Station structure.

2.3.2 TBM Drive Site

The TBM drive site would be set up using similar plant and equipment to that described for the DASP site.

The TBM would be transported in pieces of as large a size as is both permitted and practical for transport. Pieces would be assembled and the TBM tested and commissioned before starting tunnelling to the south.

It is unlikely that any of the station can be completed to base slab level before the TBM starts to arrive, but the portal extension will be sufficient to erect the TBM. The TBM will therefore need to be launched in ‘short mode’ without a full set of gantries. The remaining gantries will then be installed as the TBM mines forward.

The site would then be used for a considerable duration to support the tunnelling operation. This would largely be serviced through the portal extension (e.g. using a vertical conveyor and vertical conveyor take-up loop), so as to minimise disruption to the station works (which, after the re-opening of the road, will be serviced from relatively small sites on each side of the R108).

It is also proposed that a portion of the Northwood site is set aside as a logistics area for the receipt and consolidation of deliveries to the small city centre station and shaft sites, aiming to ensure ‘just in time’ delivery, and therefore avoid the need to store very many materials on the sites.

2.4 Tunnel Site 4: Griffith Park

The TBM will pass through 9 deep stations as it moves south from Northwood. The third of these will be Griffith Park Station. Following the completion of the tunnel south of Charlemont and the burial of the TBM, the tunnel is to be stripped out of the majority of the temporary services and cleaned and then the first stage concrete will be placed. For descriptions of these activities, see Section 5.5 and 5.6.

Griffith Park will be used to support the tunnel clean-out and first stage track bed for the section from Griffith Park to the end of the tunnel south of Charlemont. This allows the following activities to take place simultaneously:

- Clean tunnel south of Charlemont to Griffith Park and then install first stage track bed south of Charlemont to Griffith Park; and
- Clean tunnel Griffith Park to Northwood, install first stage track bed Griffith Park to Northwood and install track Northwood to Griffith Park.

During these works, the Griffith Park site will operate 24 hours a day, 7 days a week. However, the majority of these works are in the tunnel and not on site.

- During tunnel clean-out:
  - Nightshift: materials delivered to station base-slab; materials lifted to surface
  - Dayshift: as nights plus materials taken on / off site
- During track bed concrete:
  - Nightshift: site batching of concrete
  - Dayshift: as nights plus delivery and removal of materials.

2.5 Crossing Stations

The TBMs must cross all of the deep stations with the exception of Northwood. These are crossed either:

- Before the installation of the level 2 props (beneath the mezzanine slab), referred to here as 'TBM first'; or
- After the completion of the station base slab and removal of the temporary props (referred to here as 'Station first').

The TBM is on the programme critical path, stations should hold up the TBM progress. Only five stations can achieve the 'station first' scenario (Mater, O'Connell Street, Tara, St Stephen's Green and Charlemont). All other stations must wait for the TBM to pass through. Variations in the construction programme may lead to stations being changed from "Station first" to "TBM first" as required.

In the 'TBM first' scenario:

- The end diaphragm wall panels must be installed and must include a 'soft eye' of weaker concrete and GRP reinforcement.

In the 'Station first' scenario:

- The end diaphragm wall panels must be installed and could include a 'soft eye' of weaker concrete and GRP reinforcement, or the diaphragm wall panels could be broken out in advance of the TBM arrival.
- Appropriate measures must be put in place to enable the TBM cutterhead pressure and ring grouting pressure to be maintained whilst the TBM enters and leaves the station. This could involve one or more of: external grouting or slurry walls; an internal ground block; a reception can; or a simple seal can.
- A method for pushing the TBM across the station (e.g. sliding rails) must be provided.

In both cases, the continued supply of the TBM by construction railway, conveyor belt and walkway must be maintained during the remainder of the tunnel drive. This will then continue for supply of the cleanout, track bed and other follow-on activities.

2.6 TBM Burial: South of Charlemont

The TBM used to excavate the City Tunnel will complete its journey near to the Luas Green Line stop at Ranelagh. The location has been chosen to provide:

- Sufficient space beyond Charlemont station for the installation and operation of a crossover and turn-back facility; and
- A section of tunnel which could be extended further south or broken into for a future extension and connection to the Luas Green Line.

There are no good locations for a large shaft in this area, which would allow the recovery of the TBM, and so, the TBM is to be driven off-line and buried (see Section 4.10 for details).

2.7 Tunnel Strip Out and First Stage Concrete Sites

It is proposed that the clean out of the tunnels and the installation of the first stage track bed is carried out from the following sites:

- Griffith Park (for the south of Charlemont TBM burial site, back to Griffith Park);
- Northwood (for the section from Griffith Park to Northwood); and
- DASP (for the Airport Tunnel).

These operations are described in Sections 5.5 and 5.6 of this report.

These operations will take place 24 hours per day and 7 day per week.

2.8 Tunnel Fit Out Sites

It is proposed that the installation of the track, trackbed and mechanical, electric and plumbing (MEP) installations within the tunnels are carried out from the following sites:

- Estuary; and
- Dardistown Depot.

3. Geology

3.1 General Description

This description of geological conditions has been prepared based upon ground investigation data obtained to support the proposed Project.

The underlying geology of the MetroLink alignment is sedimentary rock divided north to south into five distinct formations which have in the past been subject to glacial erosion.

At the north portal of the proposed Airport Tunnel the bedrock in around 20mbgl, before rising to within a few metres of ground level in the vicinity of Dublin Airport. To the south of Dublin Airport, the bedrock level falls relatively steeply to depths of between 30mbgl and 40mbgl.

Bedrock is estimated to lie between 15mbgl and 25mbgl between the M50 and Dublin City University (DCU), with locally greater depths of more than 30mbgl at the Griffith Avenue Station, although it is noted that bedrock depth data are sparse. Between the Griffith Avenue and Mater Stations, the depth to bedrock is typically between 10mbgl and 25mbgl with depths increasing as Mater is approached.

From Mater Station to the northern end of O’Connell Street, depth to bedrock increases to between approximately 23m and 32m, as a result of a combination of a rise in ground levels and the existence of a pre-glacial channel. Bedrock level then rises to approximately 10m at O’Connell Bridge and to the south of the River Liffey depth to bedrock is typically between 7mbgl and 12mbgl.

The rock is overlain by a soil/rock transition layer and then generally a varying but mostly substantial thickness of glacial till which contains intermittent Fluvio-Glacial sand lenses.

Either side of the easterly flowing River Liffey, the till is absent, and a substantial thickness of alluvium overlies the transition layer. Immediately north of this zone, the transition layer is overlain for a significant distance by glacial sands and gravels varying in thickness between 2m and 22m. Superficial deposits of made ground occur consistently along the route.

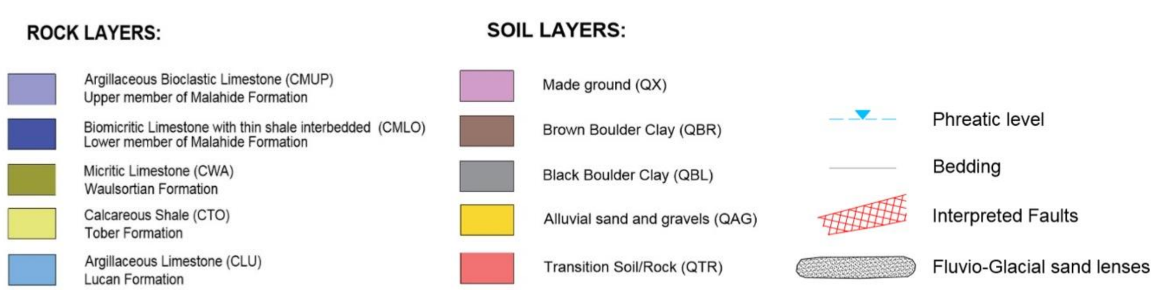


Diagram 3.1: Geology Legend for MetroLink Dublin Metro alignment

3.2 Specific Formations – Rock (Limestone)

3.2.1 Upper part of the Malahide Formation (CMUP)

The Upper Malahide Formation stratigraphically underlies the Waulsortian Formation and comprises argillaceous limestones, nodular wackestones and shales. This is the rock substrate expected to be encountered in the northern section of the Dublin Airport Tunnel. It is composed essentially of a grey to black argillaceous limestone of bioclastic origin, massive, where it is difficult to recognise the bedding planes.

The upper part of the Malahide Formation along the MetroLink alignment will be excavated mainly in fair rock mass conditions (RMR Class III), approximately 57%, whilst approximately 23% will be excavated in poor rock mass conditions (RMR Class IV). Approximately 18% will be excavated in good rock mass conditions (RMR Class II). Note that 2% of the upper part of the Malahide Formation will be excavated in very poor rock mass conditions (RMR Class V), corresponding to fracture zones.

Table 3.1. Summary of Uniaxial Compressive Strength test results for Malahide Formation

	UNIAXIAL COMPRESSIVE STRENGTH (MN/m^2)
No. OF TESTS	11
MAXIMUM	65.0
MEAN	**36.2**
MINIMUM	12.8
MEDIAN	35.1
STANDARD DEVIATION	16.8

3.2.2 The Waulsortian Formation (CWA)

The Waulsortian Limestone is described as a pale grey, commonly massive biomicrite with distinctive cavity-filling stromatactis in mound forms or complexes, with shale interbeds with depositional dips of 30° to 40° or more.

This layer is composed essentially of a light grey massive limestone, with no clear bedding, and with frequent calcite veins. The limestone is also hard and compact.

The Waulsortian Formation is more prone to karstification and is likely to be more permeable and porous than the other limestone formations. However, as will be discussed in following sections, the porosity and permeability, in this case, is lower than in other units.

The Waulsortian Formation is expected to be encountered in the proximity of Dublin Airport Station.

Table 3.2. Summary of Uniaxial Compressive Strength test results for Malahide Formation

	UNIAXIAL COMPRESSIVE STRENGTH (MN/m^2)
No. OF TESTS	11
MAXIMUM	63.8
MEAN	**47.6**
MINIMUM	29.9
MEDIAN	47.4
STANDARD DEVIATION	10.1

The Waulsortian Formation along the MetroLink alignment will be excavated mainly in fair rock mass conditions (RMR Class III), approximately 31%, whilst approximately 4% will be excavated in poor rock mass conditions (RMR Class IV). Approximately 66% will be excavated in good rock mass conditions (RMR Class II).

3.2.3 The Tober Colleen Formation (CTO)

The Tober Colleen Formation is the lowest facies of the Calp Limestone and consists of dark grey interbedded calcareous mudstone or shale and thin layers of calcilutite, calcisiltite and very argillaceous micrite, which is usually burrowed.

The Tober Colleen Formation is expected to be located between Dublin Airport and Collins Avenue.

Table 3.3.Summary of Uniaxial Compressive Strength test results for Tober Colleen Formation

	UNIAXIAL COMPRESSIVE STRENGTH (MN/m^2)
No. OF TESTS	19
MAXIMUM	93.9
MEAN	**60.5**
MINIMUM	19.5
MEDIAN	51.8
STANDARD DEVIATION	22.2

3.2.4 The Lucan Formation (CLU)

The Lucan or Calp Formation comprises a dark grey to black, fine grained, graded limestone with interbedded calcareous shale, local cherts and fossiliferous beds. It forms the rock substrate expected to be encountered from the south zone of the alignment to Collins Avenue Station.

As a result of the argillaceous nature of the Calp limestone, the formation is generally not susceptible to karstification and no major voids or cavities have been reported.

The results of testing for uniaxial compressive strength of samples for each constituent rock type are quite similar, except for those obtained on samples of siltstone. However, the standard deviation is very high for the siltstones, so it is considered more appropriate to use the value for the Limestone unit, ranging from 62MN/m2 to 150MN/m2.

Table 3.4: Summary of Uniaxial Compressive Strength (CLU)

	UNIAXIAL COMPRESSIVE STRENGTH (MN/m^2)					
	CLU (all lithologies)	ROCK TYPE				
		CALCISILTITE	LIMESTONE	MUDSTONE	SHALE	SILTSTONE
No. OF TESTS	154	1	148	3	0	2
MAXIMUM	151.9	74.0	150.0	83.7		151.9
MEAN	**62.9**	**74.0**	**62.0**	**77.3**		**103.7**
MINIMUM	10.2	74.0	10.2	73.3		55.5
MEDIAN	61.5	74.0	60.6	75.0		103.7
STANDARD	28.4		28.0	5.6		68.2

The Lucan Formation along the MetroLink alignment will be excavated mainly in fair rock mass conditions (RMR Class III), approximately 75%, whilst 17% will be excavated in poor rock mass conditions (RMR Class IV). A small portion of the alignment (approximately 8%) will be excavated in good rock mass conditions (RMR Class II).

3.3 Soil/Rock Transition Layer (QTR)

This lithological unit corresponds to the contact zone between the overlying glacial till and the uppermost zone of rock, which is usually highly weathered.

The reason for treating this as a separate geological unit, being composed of both soil and rock, is due to its geotechnical behaviour. This unit should have a similar mechanical behaviour, with a mixture of boulders, sand and clay (in the case of the glacial till) and fragments of rock with fractures infilled with clay or sand (in the case of the rock).

The contact between the glacial deposits (Dublin Boulder Clay) and the underlying Carboniferous rocks shows very poor geotechnical properties. The geological-geotechnical-hydrogeological reasons for this are as follows:

a) Within the basal glacial deposits there are many sand and gravel layers, which are cohesionless, along with the presence of large erratic boulders up to 5 meters in diameter.

b) The facies variability in the glacial sediments is greater at the base of the sequence, with rapid changes over very short distances (as little as a few centimetres).

c) The glacial sediments were deposited over the topography which was developed thousands of years before the glacial age. For this reason, the carboniferous rocks are weathered in the first 2-5 meters, with a soil geotechnical characterization.

d) In many locations the contact between the glacial sediments and the original topography is inclined and may therefore be conducive to landslides.

e) During the glacial age there was a preferential water circulation within the Soil/Rock Transition layer, where fine sediments were washed out from the basal glacial deposit and also the uppermost zone of the weathered rock.

f) This layer comprises material which has a very high porosity and permeability, forming one of the principal aquifers beneath Dublin.

g) The groundwater flowing through this layer is an additional factor in the poor geotechnical behaviour of this soil.

3.4 Glacial Till

3.4.1 Black Boulder Clay

The QBL unit is the second most common drift deposit represented along the alignment. It predominantly appears between the M-50 route up to the Seatown area. The thickness, as in the case of the Brown Boulder Clay (QBR), is quite variable but the maximum thickness detected reaches close to 40 m, 1 kilometre south of the airport.

This unit consists of a dark grey, slightly sandy clay, with some gravel and cobbles. It is typically up to 36m thick. Locally, there are silt / gravel lenses and large boulders up to 5 meters thick. It is important to highlight the high compositional variability of this soil, with clay, sand, gravel and boulders in different proportions and within short distances. The composition is similar to the Brown Boulder Clay (QBR) but is different in colour.

As the difference in thickness is very important depending of the location, a comparative analysis of all the available data has been performed in order to determine if there are significant variations in relation to depth.

Black Boulder Clay (QBL >10m)

This unit is composed of a stiff to very stiff, grey to dark grey, slightly sandy clay, with some gravel and cobbles. Locally, there are silt / gravel lenses and large boulders up to 5 meters thick. The unit exhibits significant variability in composition, with clay, sand, gravel and boulders in different proportions and within short distances.

Black Boulder Clay (QBL <10m)

This unit occurs from ground level to depths of up to 10 m. It is composed of grey and dark, slightly sandy clay, with some gravel and cobbles. Locally, there are silt / gravel lenses and large boulders up to 5 meters thick.

3.4.2 Brown Boulder Clay

This unit is composed of a stiff to very stiff, brown, slightly sandy clay, with some gravel and cobbles. Locally, there are silt / gravel lenses and large boulders, up to 5 meters thick. It exhibits significant variability in composition, with clay, sand, gravel and boulders in different proportions and within short distances.

Brown Boulder Clay (QBR <10 m)

This unit occurs from ground level to depths of up to 10 m, and is composed of brown, slightly sandy clay, with some gravel and cobbles. Locally, there are silt / gravel lenses and large boulders, up to 5 meters thick.

Brown Boulder Clay (QBR)

The glacial till that covers the Dublin area is commonly known as the Dublin Boulder Clay (DBC) which is the primary superficial deposit overlying bedrock in Dublin. DBC is characterised by a relatively simple microstructure with low water content, void ratio, permeability and high density (Long and Menkiti).

Farrell et al. (1995a) made the differentiation between the Brown Boulder Clay and the Black Boulder Clay. Farrell and his co-authors stated that the (Upper) Brown Boulder Clay is a weathering product of the Black Boulder Clay but is broadly similar to it in terms of particle size distribution. These researchers also briefly note that there appears to be some local variation in the colour of the Black Boulder Clay, as it is locally brown.

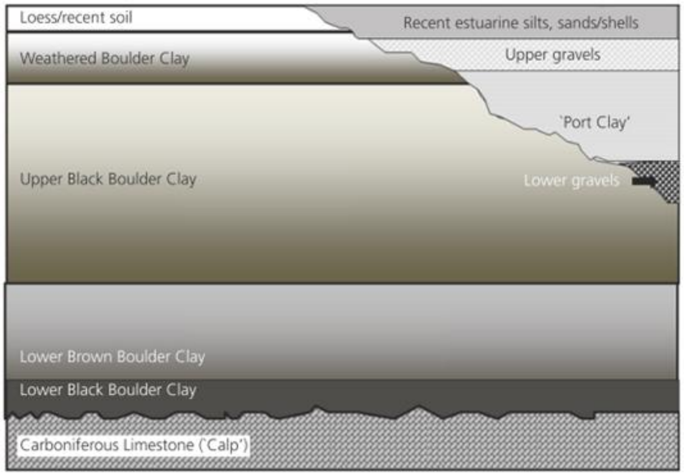


Diagram 3.2: Simplified schematic of the interpreted stratigraphy of the DBC (Skipper et al., 2005)

QBR is the most common superficial strata present along the alignment. It predominantly appears in the southern half of the alignment up to the crossing of the M-50 route. The thickness is quite variable, with the maximum located between the north of the River Liffey and Whitworth area, reaching more than 30 m. In addition to the pre-glacial sands and gravels located north of the River Liffey, two geotechnical units exhibiting granular behaviour have been established (QBRs<10m and QBRs>10m), delimitated between chainages 14+700 and 16+050.

As the depth of this stratum varies through the various zones along the alignment, the data has been broken down into sub-groups by depth of deposit to establish any trends.

This section looks at the QBR lithology holistically, without taking into account the depth of the deposit.

3.4.3 Glacial Sands and Gravels

Pre-Glacial Sands & Gravels (QBRs>10m). Chainages 14+700 and 16+000

This geotechnical unit is defined below 10m depth and is found underlying the Pre-glacial Sands and Gravels (QBRs<10m) northwards from the River Liffey area, and along O'Connell Street. It has been delimitated between chainages 14+700 and 16+000.

The thickness of the glacial sands and gravels encountered to the north of the River Liffey varied between 2m and 22m. The granular layers generally consisted of medium dense to very dense, occasionally clay bound, occasionally silty, sandy gravel/gravelly sand/sand and gravel with cobbles and occasional boulders. Groundwater strikes, or seepage, were commonly observed within the granular layers.

Pre-Glacial Sands & Gravels (QBRs<10m). Chainages 14+700 and 16+000

This unit is found underlying the mainly Brown Boulder Clay (QBR) comprising a significant thickness of glacial sands and gravels, with less frequent clayey glacial till, present in the area near the River Liffey and along O'Connell Street. It has been delimitated between chainages 14+700 and 16+000.

The thickness of the glacial sands and gravels encountered to the north of the River Liffey varied between 2m and 22m. The granular layers generally consisted of medium dense to very dense, occasionally clay bound, occasionally silty, sandy gravel/gravelly sand/sand and gravel with cobbles and occasional boulders. Groundwater strikes, or seepage, were commonly observed within the granular layers.

The estimated average thickness of this unit is about 5 to 8 meters, although locally this may extend to 22 meters. The glacial sands & gravels consists of soft to firm gravelly clay interbedded with layers of loose to dense sand and gravels. The presence of cobbles and boulders is also frequently noted.

Diagram 3.3: Fluvioglacial Sands & Gravels in borehole MGIBH637

3.4.4 Alluvial and Fluvioglacial sediments (QAG)

This lithology is less widespread along the alignment. It is located predominantly around the River Liffey although it also appears in the far north of the alignment (along the Ward River).

The estimated average thickness of the alluvium is about 5 to 8 meters, although locally this may extend to 12 meters. The alluvium generally consists of soft to firm gravelly clay interbedded with layers of loose to dense sand and gravel. The presence of cobbles and boulders has also been frequently noted.

3.4.5 Made Ground

Made ground encountered along the MetroLink alignment is quite variable in nature. It includes heterogeneous materials selected to build embankments (i.e. M50 route) comprising sand, gravel or clay fill with many cobbles, boulders, brick, glass, ceramics and/or concrete.

The thickness of made ground varies significantly, reaching up to 6 meters, but a typical mean representative value would be around 2 meters. The main variations in thickness occur in the northern zone, where made ground may be locally absent, and in the city centre, especially around the River Liffey, where the thickness could exceed 4m.

3.5 Tunnel Geotechnical Features

The main geotechnical features for both tunnels are described below; with the first tunnel being below Dublin Airport and the second tunnel running below Dublin City.

3.5.1 Dublin Airport Tunnel

This tunnel is expected to run below the airport between chainages 5+320 & 7+560. The proposed Top of Rail elevations range from 44.131mOD to 35.959mOD.

The tunnel cover has a minimum thickness of 8.5m at the north portal and maximum of 19m at the lowest point south of the Airport.

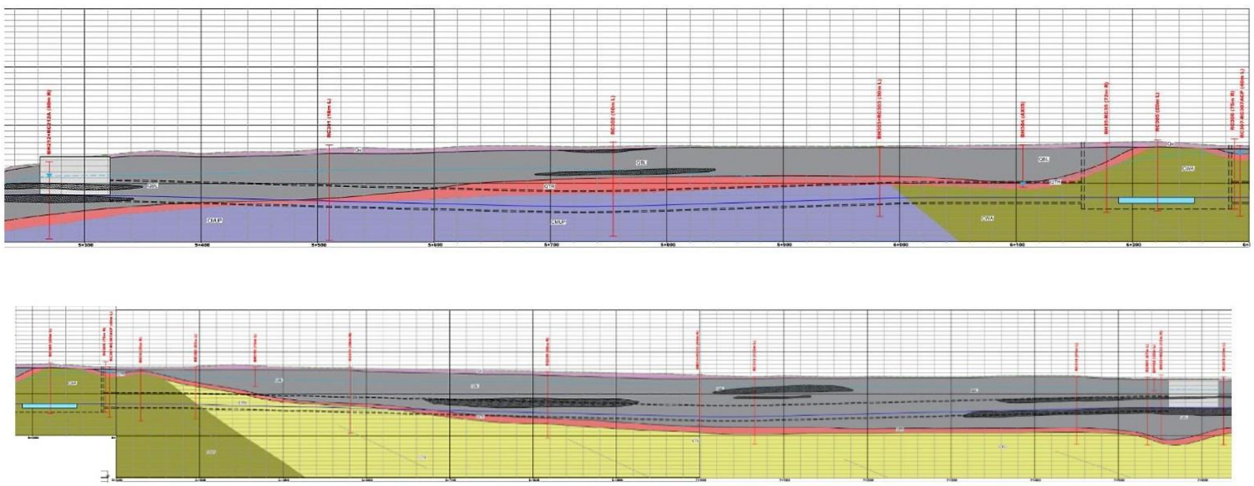


Diagram 3.4: Geologic Profile for the Dublin Airport Tunnel

Geology

Overlying the bedrock is a homogeneous layer of Black Boulder Clay (QBL) along with the Transition Soil/Rock Layer (QTR).

With regards to the bedrock, excavations are anticipated in the upper part of the Malahide Formation (CMUP) up to chainage 6+000, followed by the Waulsortian (CWA) formation up to 6+400, and then the Tober Colleen Formation (CTO) to chainage 7+560.

3.5.2 Dublin City Tunnel

The proposed City Tunnel starts at the Northwood Station portal, approximately 600m south of the M50. It runs, in a generally southerly direction, under the suburban surroundings of the R108 and continues beneath the City Centre to terminate underground south of Charlemont, in a position to enable the future connection to the existing Luas Green Line Station at Beechwood.

The City Tunnel will carry the MetroLink passenger railway in nine consecutive tunnel drives linking the Deep Stations with an additional drive housing the rail turnaround and continuing to the proposed TBM burial site. The route and geology of these drives is described in the subsequent sub-sections, which for clarity are described as follows:

- C1 Northwood to Ballymun
- C2 Ballymun to Collins Avenue
- C3 Collins Avenue to Griffith Park

- C4 Griffith Park to Glasnevin
- C5 Glasnevin to Mater
- C6 Mater to O'Connell Street
- C7 O'Connell Street to Tara Station
- C8 Tara Station to Saint Stephens Green
- C9 Saint Stephens Green to Charlemont
- C10 Charlemont to south of Charlemont TBM burial site

3.6 Tunnel alignment

The anticipated ground conditions for the City Tunnel are summarised as Diagram 3.5.

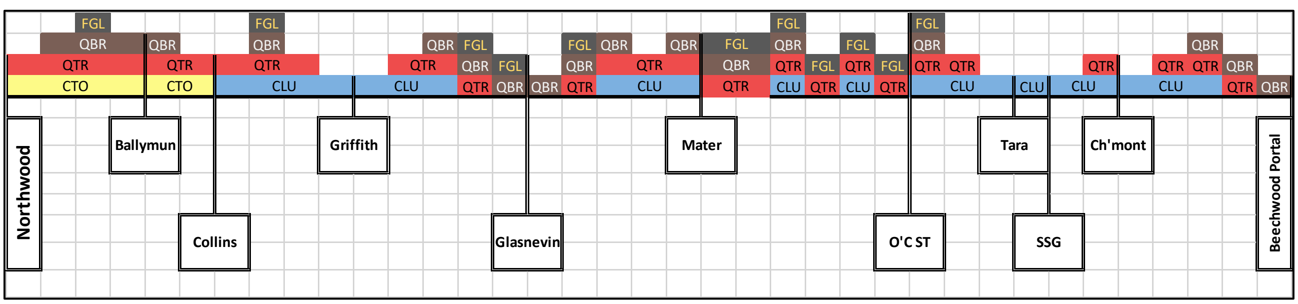


Diagram 3.5: Geology Units to be Encountered Along Alignment on the City Drive

3.6.1 Section C1: Northwood to Ballymun

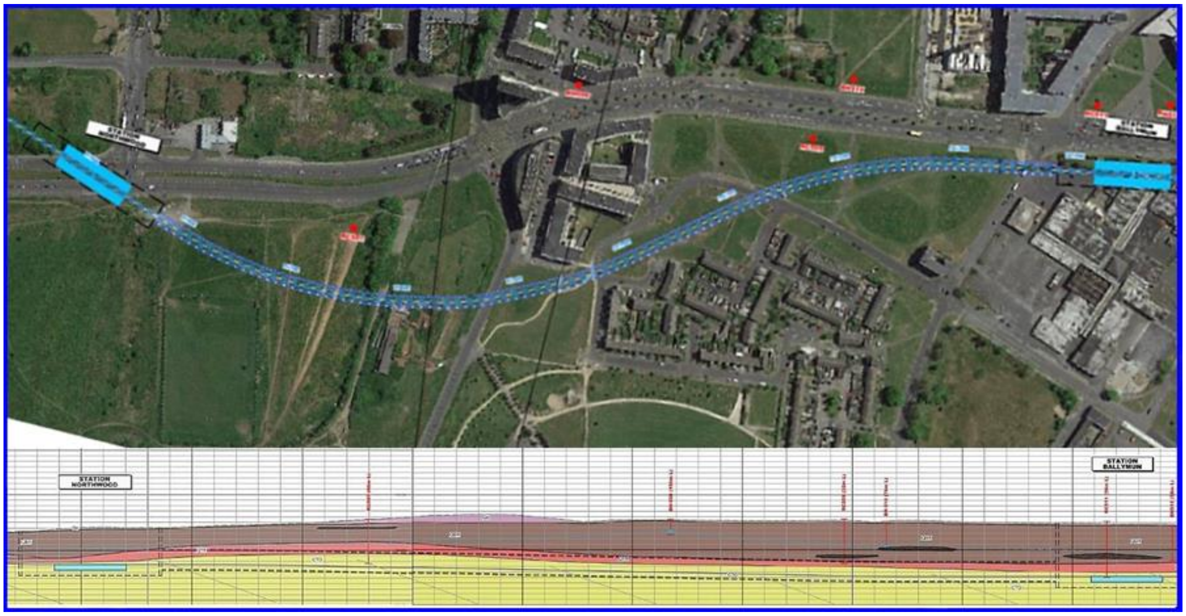


Diagram 3.6: Geologic Profile for TBM Drive C1: Northwood to Ballymun

Drive C1 starts from the portal at Northwood Station and proceeds southwards to Ballymun Station passing under open ground for approximately 320m before crossing under the R104, which contains a number of utilities including gas and water distribution mains. Continuing under open ground the drive travels for a further 200m between two groups of low-rise accommodation passing close to but not under the easterly one of them. The final 300m of the drive passes under a new development of student accommodation and a supermarket currently being constructed before crossing beneath Shangan Road, which contains a number of utilities including gas and water distribution mains, immediately north of Ballymun Station box.

At Northwood portal, the tunnel invert is 18.5m below ground level. The lower half of the tunnel face is in the Tober Colleen Formation (CTO) rock with the upper half in the water bearing Soil Rock Transition (QTR). The CTO rises gradually up the face over the first 200m of the drive until the rock reaches the brow of a local rolling peak in the formation, where the QTR interface is at the crown of the tunnel.

Over the next 210m of drive, as the tunnel grade descends at 1.0%, the surface of the CTO falls away gradually to the lower half of the face with the QTR remaining above. The overlying Brown bolder Clay (QBR) then appears at the crown of the tunnel. This face distribution is maintained for 190m after which the QBR contains lenses of Fluvioglacial Lenses (FGL), above but potentially not within the tunnel horizon, for a further distance of 60m. The remaining 160m of the drive continues to skirt the underside of the QBR, with the CTO now again falling away gradually to occupy the lower third of the face at the junction with the north headwall of Ballymun Station, where tunnel invert is 24.5m below ground level.

Table 3.5: Summary of Face Conditions Drive C1

Northwood - Ballymun						
Distance	**Length**	**Face Conditions**				**Grade %**
49	49					FLAT
119	70	CTO	QTR			T
410	291					
600	190	CTO	QTR	QBR		-1
617	17	CTO	QTR	QBR	FGL	
660	43					T
687	27	CTO	QTR	QBR		
827	140					FLAT

3.6.2 Section C2: Ballymun to Collins Avenue

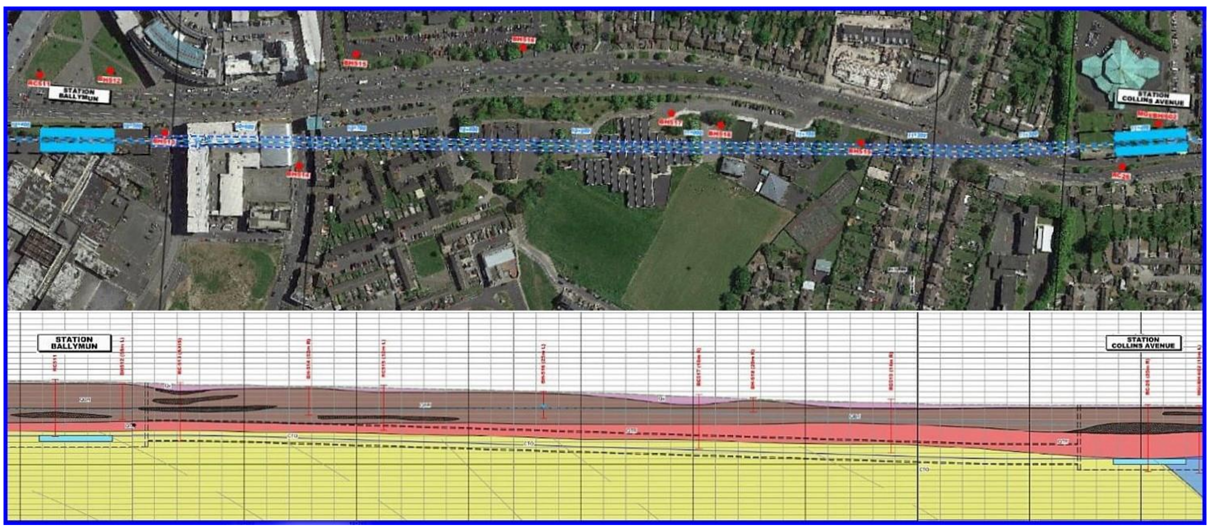


Diagram 3.7: Geologic Profile for TBM Drive C2 Ballymun to Collins Avenue

Drive C2 launches from the south headwall of Ballymun Station and drives on an approximately straight horizontal alignment to Collins Avenue Station. For approximately 30m immediately south of the station box, the drive crosses under open ground and a local access road containing utilities before passing for a further 90m beneath a mixed-use low-rise block and separate metal and glass building housing a swimming pool and gym. After crossing under Gateway Crescent and utilities, the drive passes beneath low rise residential properties and gardens for around 110m to cross under Gateway Avenue with utilities. The drive continues for 400m beneath a number of single storey education facilities, a library, open ground and dwellings to reach the junction of Glasnevin Avenue and Ballymun Road. The junction contains a large number of significant utilities including gas and water. The drive crosses it obliquely for approximately 100m to arrive at the north wall of Collins Avenue station box on the eastern side of Ballymun Road.

The first 175m of the drive is a mixed face of CTO occupying the lower half of the excavation with QTR in the upper half and QBR at the crown. As the vertical alignment descends at a grade of 1.5%, the face moves below the contact zone between the QTR and QBR. The CTO rockhead undulates gently through the upper half of the face reaching a peak about 1m from the crown for a distance of around 500m. Over the final 165m of the drive, the CTO rockhead dips to the lower half of the face.

Table 3.6:Summary of Face Conditions Drive C2

Ballymun - Collins Avenue						
Distance	Length	Face Conditions				Grade %
32	32					FLAT
84	52	CTO	QTR	QBR		T
175	91					-1.5
728	553					
780	52	CTO	QTR			T
842	62					FLAT

3.6.3 Section C3: Collins Avenue to Griffith Park

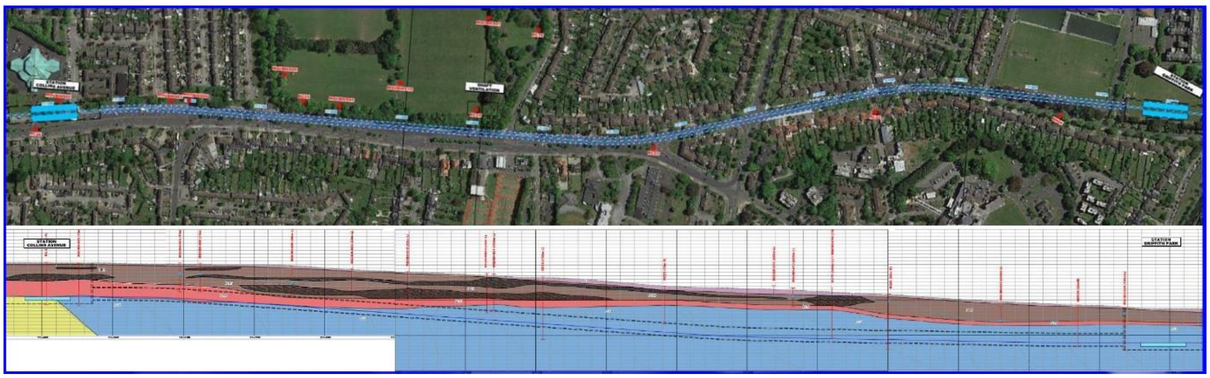


Diagram 3.8: Geologic Profile for TBM Drive C3- Collins Avenue to Griffith Park

Drive C3 launches from the south headwall of Collins Avenue Station box within which the steeply dipping interface between the CTO and CLU occurs. The lower quarter of the Tunnel face is in the rock with the remainder occupied by a thick band of QTR. As the drive begins to descend at 3.5%, the rockhead moves lower in the face before returning to the quarter point 230m into the drive where the QTR reduces in thickness and BGR appears at the crown. The face contacts the base of the BGL for around 120m with a thick lens of FGL indicated about 2m overhead. Thereafter, the CLU rock head and QTR level out as the drive continues to descend with the rock rising to a full face in a further 160m. The face continues at this grade wholly in rock for a further 350m before the rate of descent reduces to 1% for the remaining 590m to the north headwall of Griffith Park Station.

C3 is the longest single drive of the City Tunnels. It starts at the south headwall of Collins Avenue station box and runs on a generally straight horizontal alignment beneath the southbound carriageway and eastern verge of Ballymun Road for approximately 550m to the junction with Hampstead Avenue. The drive continues for around 550m under the south bound carriageway as Ballymun Road narrows towards the junction with Glasnevin Avenue (R102) and then follows Mohbi Road passing beneath the eastern footway and garden frontages of residential properties to the junction with Stella Avenue. For the remaining 400m the drive follows the curve of Mohbi Road the eastern footway and residential frontages as far as the entrance to Scoil Chaitriona before continuing under the grounds and entrance of Na Fianna CLG and the adjoining Scoil Mobhi to the north headwall of Griffith Park Station box.

Table 3.7. Summary of Face Conditions Drive C3

<table>
<tr><th colspan="7">Collins Avenue - Griffith Park</th></tr>
<tr><th>Distance</th><th>Length</th><th colspan="4">Face Conditions</th><th>Grade %</th></tr>
<tr><td>39</td><td>39</td><td rowspan="3">CLU</td><td rowspan="3">QTR</td><td></td><td></td><td>FLAT</td></tr>
<tr><td>162</td><td>123</td><td></td><td></td><td>T</td></tr>
<tr><td>230</td><td>68</td><td></td><td></td><td rowspan="4">-3.5</td></tr>
<tr><td>350</td><td>120</td><td>CLU</td><td>QTR</td><td>QBR</td><td></td></tr>
<tr><td>510</td><td>160</td><td>CLU</td><td>QTR</td><td></td><td></td></tr>
<tr><td>864</td><td>354</td><td rowspan="5">CLU</td><td></td><td></td><td></td></tr>
<tr><td>952</td><td>88</td><td></td><td></td><td></td><td>T</td></tr>
<tr><td>1338</td><td>386</td><td></td><td></td><td></td><td>-1</td></tr>
<tr><td>1398</td><td>60</td><td></td><td></td><td></td><td>T</td></tr>
<tr><td>1468</td><td>70</td><td></td><td></td><td></td><td>FLAT</td></tr>
</table>

3.6.4 Section C4: Griffith Park to Glasnevin

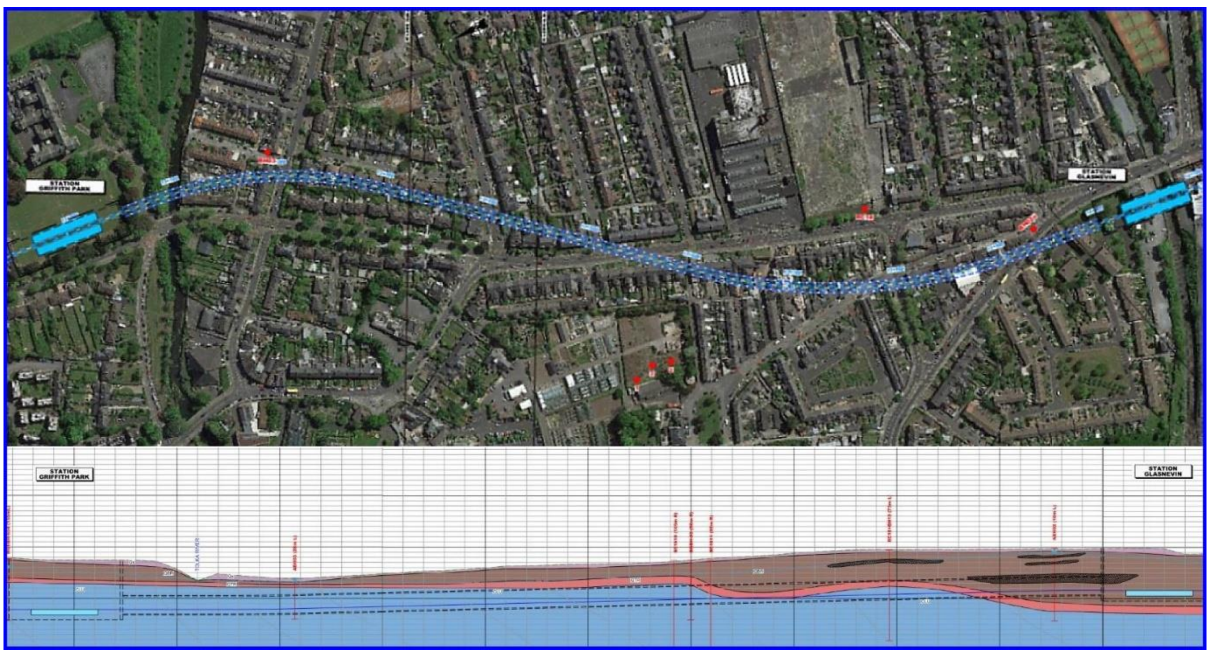


Diagram 3.9: Geologic Profile for TBM Drive C4- Griffith Park to Glasnevin

C4 drive launches from the south headwall of Griffith Park Station box in a full face of CLU. After 150m on the level, the grade rises for 400m and the tunnel crown gradually approaches the rockhead. The Garde is maintained as for a further 150m the tunnel crown is in contact with or close to the base of the QTR. The rockhead now dips steeply to tunnel axis over a distance of 20m with the upper face fully in the QTR. QBR now appears at the crown overlying an approximately 3m band of QTR which moves down the face as the dip in the rockhead slackens. The distribution is maintained as the rock gently undulates over a distance of 240m. The grade is still rising as the tunnel leaves CLU encounters an increasing thickness of QBR with FGL in the upper face of a distance of 40m. The remaining 90m of drive is in QBR with FGL in the upper third as the grade levels out on the approach to Glasnevin Station.

Drive C4 launches from the south headwall of Griffith Park station box and within the first 60m crosses under the entrance to Whitehall College and the channel housing the Tolka River. For approximately 400m the drive curves to a general south westerly direction running parallel to Saint Mobhi Road passing beneath residential properties and gardens and including crossings under Botanic Avenue and Fairfield Road to reach the junction of Cliftonville Road and Botanic Road. The drive passes under the junction and Botanic Road at an oblique for approximately 70m before curving in a southerly direction for around 200m crossing beneath St Teresa'a Road, and residential properties to Prospect Avenue. Following an oblique passage of around 25m under Prospect Avenue the drive continues for a further 120m crossing beneath a residential garden, square under Prospect Way, further residential gardens, a commercial warehouse, a brick built creche premises and a rear residential entrance to Finglas Road. After crossing Finglas Road obliquely for around 20m the drive continues under a row of 2 storey commercial properties and the end of a three-storey residential block for the final 60m to the north headwall of Glasnevin Station box.

Table 3.8: Summary of face conditions Drive C4

<table>
<tr><th colspan="7">Griffith Park - Glasnevin</th></tr>
<tr><th>Distance</th><th>Length</th><th colspan="4">Face Conditions</th><th>Grade %</th></tr>
<tr><td>145</td><td>145</td><td rowspan="3">CLU</td><td></td><td></td><td></td><td>FLAT</td></tr>
<tr><td>215</td><td>70</td><td></td><td></td><td></td><td>T</td></tr>
<tr><td>550</td><td>335</td><td></td><td></td><td></td><td rowspan="3">1</td></tr>
<tr><td>570</td><td>20</td><td>CLU</td><td>QTR</td><td></td><td></td></tr>
<tr><td>670</td><td>100</td><td rowspan="3">CLU</td><td rowspan="3">QTR</td><td rowspan="3">QBR</td><td></td></tr>
<tr><td>770</td><td>100</td><td></td><td>T</td></tr>
<tr><td>810</td><td>40</td><td></td><td rowspan="3">FLAT</td></tr>
<tr><td>850</td><td>40</td><td>QTR</td><td>QBR</td><td>FGL</td><td></td></tr>
<tr><td>949</td><td>99</td><td>QBR</td><td>FGL</td><td></td><td></td></tr>
</table>

3.6.5 Section C5: Glasnevin to Mater

C5 launches from Glasnevin with a full face of QBR which continues for 210m after which QTR enters at invert and steadily climbs to tunnel axis over a distance of 50m accompanied by lenses of FGL close above the tunnel crown. CLU then enters at tunnel invert rising gradually up the face overlain by an approximately 3m band of QTR and the QBR interface receding towards the tunnel over the tunnel invert and a gradually thickening band of QTR above continues with the rock gently falling away to the lower third for 220m until QBR appears at the tunnel crown. This sequence remains for the final 105m of the drive with the rock falling to approximately 1m above tunnel invert.

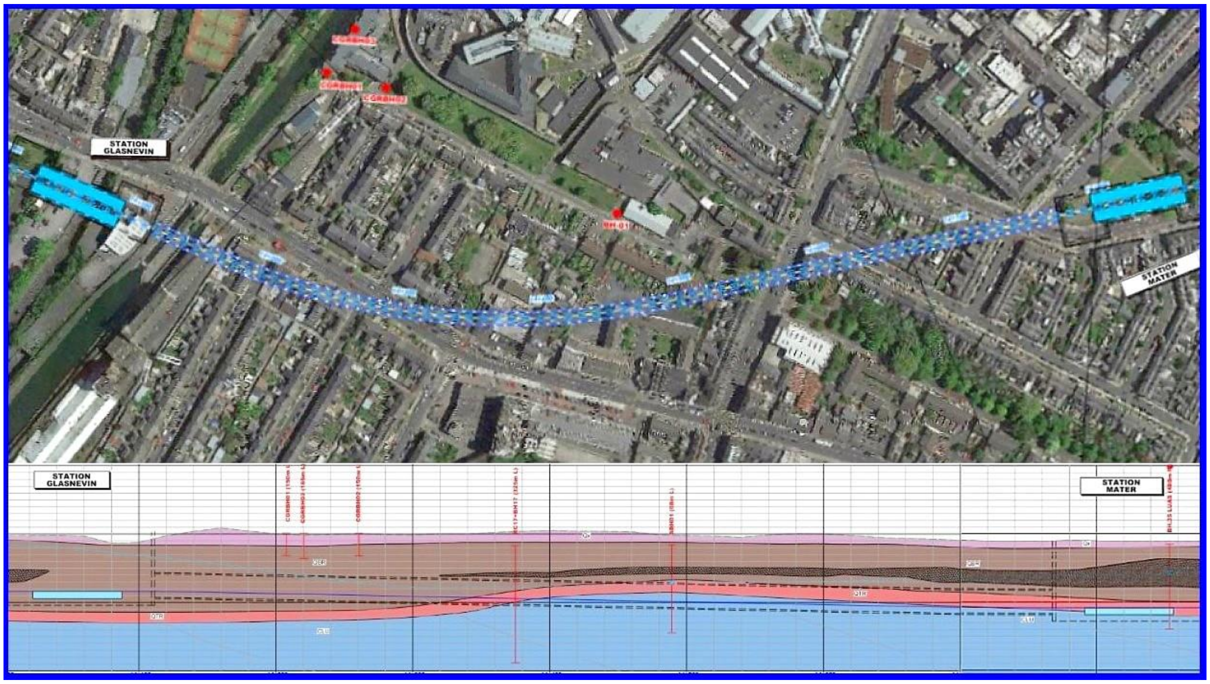


Diagram 3.10: Geologic profile for TBM drive C5- Glasnevin to Mater

For the first 25m following launch from the south headwall of Glasnevin Station box C5 drive passes beneath the Royal Canal Way tow path, the central lock gates of a two-chamber serviceable canal lock and the southern Phibsborough Road tow path. Curving in a south easterly direction the drive passes for approximately 60m under the end of a three-storey residential block, the corner of a three storey commercial premises, a local access road and the rear of two storey residential properties to reach Leinster Street North. Continuing on a curve for around 70m the drive passes beneath Leinster Road North and a row of two storey residential properties the west side of the junction between Munster Road and Phibsborough Road.

The drive crosses under the junction and Phibsborough Road obliquely for around 50m before passing beneath a row of two storey residential properties, Devery's Road and a collection of light industrial and commercial premises for a further 100m. The drive continues under the grounds and one corner of a four-storey residential block, row of two storey residential properties and the grounds of Phibsborouh Library for approximately 150m to reach the North Circular Road. The final length of the drive is straight in a generally south westerly direction with a 25m inclined crossing under the North Circular Road, 20m beneath a corner block of three storey mixed use premises, a 15m inclined crossing under Goldsmith Street, 100m passing under a block of generally two storey residential properties and gardens and a 40m oblique passage under the offset junction between Berkley Road, St Vincent Street North and Eccles Street to the north headwall of Mater Station box.

Table 3.9:Summary of Face Conditions Drive C5

<table>
<tr><th colspan="7">Glasnevin - Mater</th></tr>
<tr><th>Distance</th><th>Length</th><th colspan="4">Face Conditions</th><th>Grade %</th></tr>
<tr><td>197</td><td>197</td><td>QBR</td><td></td><td></td><td></td><td>FLAT</td></tr>
<tr><td>247</td><td>50</td><td>QTR</td><td>QBR</td><td>FGL</td><td></td><td rowspan="2">T</td></tr>
<tr><td>297</td><td>50</td><td rowspan="2">CLU</td><td rowspan="2">QTR</td><td rowspan="2">QBR</td><td></td></tr>
<tr><td>322</td><td>25</td><td></td><td rowspan="2">-1</td></tr>
<tr><td>406</td><td>84</td><td rowspan="3">CLU</td><td rowspan="3">QTR</td><td></td><td></td></tr>
<tr><td>496</td><td>90</td><td></td><td></td><td>T</td></tr>
<tr><td>542</td><td>46</td><td></td><td></td><td rowspan="2">FLAT</td></tr>
<tr><td>661</td><td>119</td><td>CLU</td><td>QTR</td><td>QBR</td><td></td></tr>
</table>

3.6.6 Section C6: Mater to O'Connell Street

Diagram 3.11: Geologic Profile for TBM Drive C6- Mater to O'Connell Street

C6 Launches from Mater Station box on the level for a distance of 80m skirting the CLU rockhead in a mixed face of QTR below tunnel axis and QBR above and a zone of FGL up to 10m thick immediately above the tunnel. At a point where the rockhead falls away the tunnel also starts to descend and FGL enters at the tunnel crown. Towards the middle of the next 160m the QTR dips below tunnel formation for 40m and returns to the face, rising gradually to occupy the lower third. As the tunnel encounters the CLU rockhead at invert the FGL descends gradually reducing the thickness of QBR over the course of 60m until it disappears 10m before the rockhead dips steeply away below the tunnel. Over the next 100m the top of the QTR falls gradually down the tunnel face with the FGL occupying the upper three quarters retreating to tunnel axis at a point where the CLU re-enters at tunnel invert. This sequence is maintained over the next 360m with the proportion of the face occupied by each element varying substantially as the interfaces ripple. The final 130m of the drive is above the rockhead with most of the face in the FGL.

Immediately after launch from the south headwall of Mater station box Drive C6 passes east of the tower and beneath the nave of St Joseph's Carmelite church and continues under a row of two residential properties for around 60m. For a further 40m the drive crosses beneath Berkeley Avenue, the rear of a row of two storey commercial premises and under a terrace of three storey plus base properties on Nelson Street possibly dating from the early nineteenth century. For a distance of approximately 130m the drive passes first under Nelson Street than crossing beneath similar properties on the south side and at the rear of a terrace facing Berkley Street to mine under those on Blessington Street where the terrace becomes four stories plus basement. An oblique crossing under Blessington Street of approximately 100m includes to the south an oblique passage under a relatively modern five storey mainly residential block at the junction with Dorset Street. The drive continues for approximately 22m with a relatively perpendicular crossing under Dorset Street.

For approximately 75m from the junction of Dorset Street and North Fredrick Street the drive curves in an easterly direction passing partially a three-storey public house and the frontages of a terrace of four storey plus basement properties to cross North Fredrick Street obliquely to the junction with Hardwicke Street. South of this junction the drive continues on a curve passing partially under the frontages of a terrace of four and five storey plus basement properties for approximately 110m to the junction of Fredrick Street North and Gardiner Row. Continuing on a curve for approximately 125m from the junction the drive passes tangentially to four storey buildings at the south east corner and then crosses Parnell Square East to the western side of the road. The drive has a straight horizontal alignment as it passes arear entrance to the Rotunda Hospital and the Gate Theatre for around 140m to Parnell Street. Following a relatively perpendicular crossing of approximately 20m under Pernell Street the drive passes square beneath a row of three storey commercial properties and a demolition site for the final approach to the north headwall of O'Connell Street station box.

Table 3.10:Summary of Face Conditions Drive C6

<table>
<tr><th colspan="7">Mater - O'Connell Street</th></tr>
<tr><th>Distance</th><th>Length</th><th colspan="4">Face Conditions</th><th>Grade %</th></tr>
<tr><td>41</td><td>41</td><td rowspan="3">QTR</td><td rowspan="3">QBR</td><td rowspan="3">FGL</td><td></td><td>FLAT</td></tr>
<tr><td>131</td><td>90</td><td></td><td>T</td></tr>
<tr><td>240</td><td>109</td><td></td><td rowspan="4">-2.5</td></tr>
<tr><td>310</td><td>70</td><td>CLU</td><td>QTR</td><td>QBR</td><td>FGL</td></tr>
<tr><td>410</td><td>100</td><td>QTR</td><td>FGL</td><td></td><td></td></tr>
<tr><td>706</td><td>296</td><td rowspan="2">CLU</td><td rowspan="2">QTR</td><td rowspan="2">FGL</td><td></td></tr>
<tr><td>770</td><td>64</td><td></td><td rowspan="2">T</td></tr>
<tr><td>796</td><td>26</td><td rowspan="2">QTR</td><td rowspan="2">FGL</td><td></td><td></td></tr>
<tr><td>891</td><td>95</td><td></td><td></td><td>FLAT</td></tr>
</table>

3.6.7 Section C7: O’Connell Street to Tara

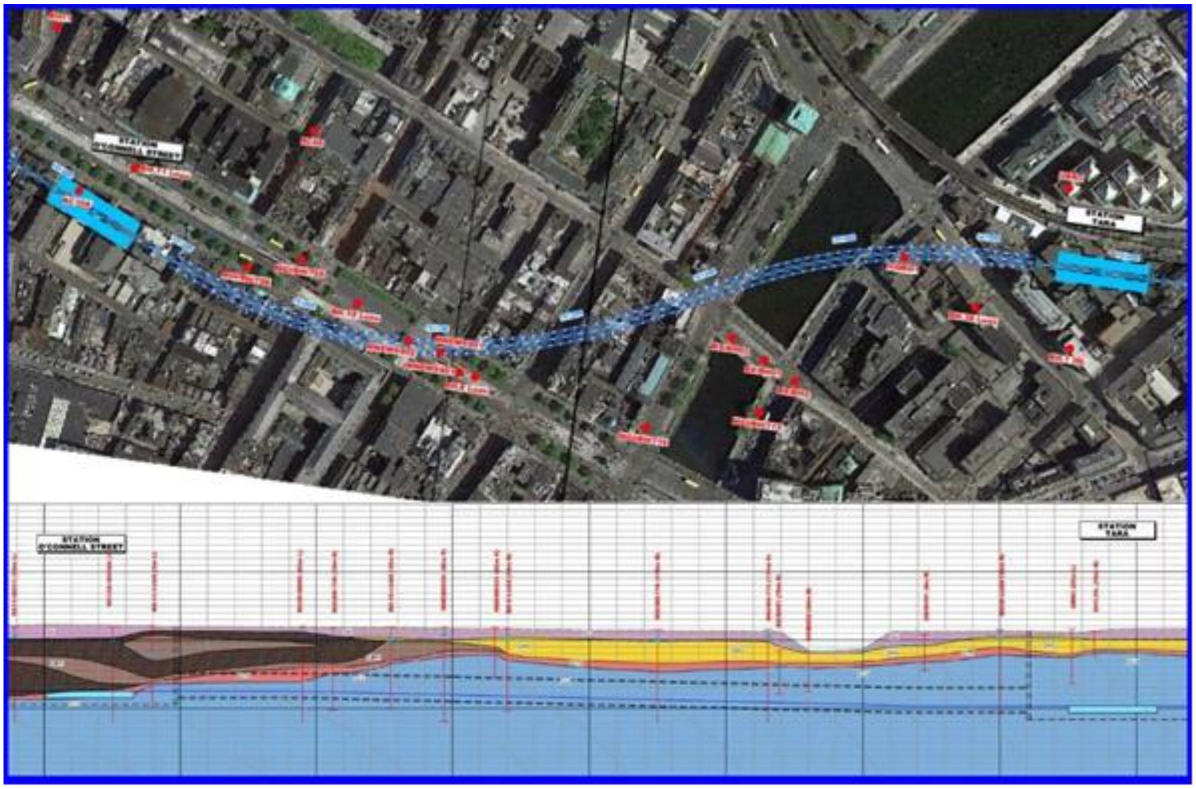


Diagram 3.12: Geologic Profile for TBM Drive C7- O’Connell Street to Tara

C7 launches with the CLU rockhead above tunnel axis with QTR overlying and FGL in the upper 1m. Over the first 45m the rockhead remains level above axis but the top of the QTR rises to the tunnel crown. A mixed face of CLU and QTR continues for a further 60m until the rockhead rises to occupy the full face over a distance of 20m. The remaining 500m of the drive are in a full face of CLU.

Drive C7 launches from the south headwall of O’Connell Street station box at the start of a curve in an easterly direction and passes for around 90m beneath a row of four storey commercial premises to Henry Street which it crosses below relatively square of around 14m. after passing under the north east corner of the GPO façade. There follows an oblique crossing of around 115m to the east side of O’Connell Street on the south side of the junction with Sackville Street. The drive continues for 50m beneath a block of five storey commercial premises and a 30m oblique crossing of Abbey Street. The alignment is straight for a passage of approximately 85m under a block of generally four storey commercial premises to Marlborough Street immediately north of the junction with Eden Quay.

Crossing obliquely under Marlborough Street and Eden Quay for 40m the drive arrives at the north wall of the River Liffey. The drive starts to curve south during the river crossing of approximately 80m. After passing under the south wall of the River then crosses beneath George’s Quay obliquely for around 30m and a further 40m under a block of four storey and two storey commercial premises to Tara Street. A 30m oblique crossing under Tara Street is followed by a 30m passage under a building development and Poolbeg Street to reach the north headwall of Tara station box.

Table 3.11: Summary of Face Conditions Drive C7

O'Connell Street - Tara						
Distance	Length	Face Conditions				Grade %
45	45	CLU	QTR	QBR	FGL	FLAT
75	30					
111	36	CLU	QTR			T
125	14					-1.2
526	401					
562	36	CLU	QTR			T
636	74					FLAT

3.6.8 Section C8: Tara Station to St Stephen's Green

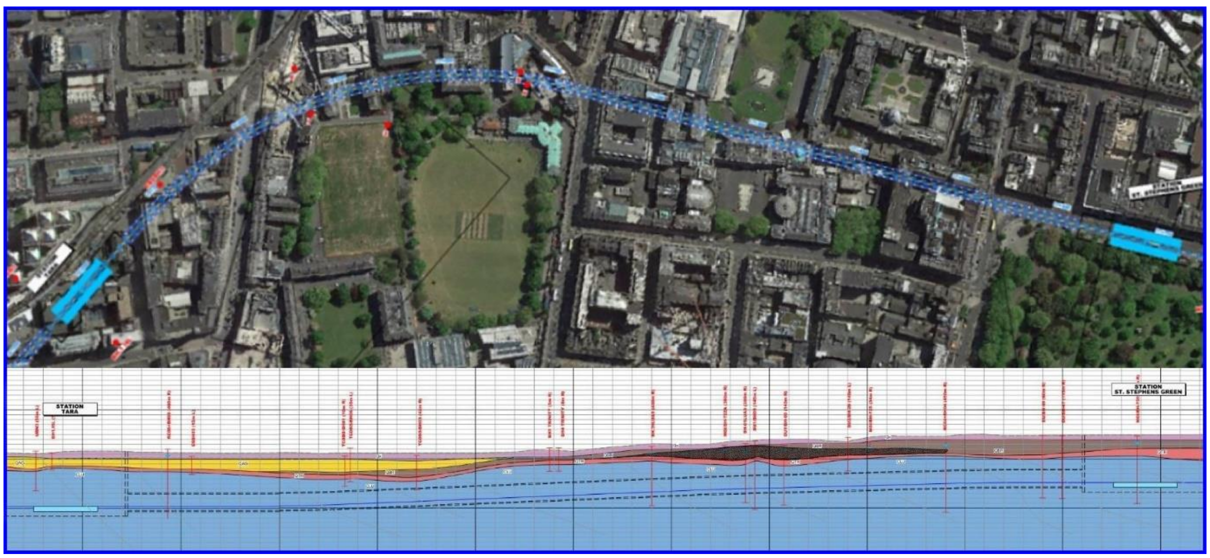


Diagram 3.13: Geologic Profile for TBM Drive C8- Tara Station to St Stephen's Green

C8 drives with a full face of CLU over its whole 980m length.

Drive C8 launches onto a curve from the south headwall of Tara station box with a 20m oblique crossing under Townsend Street followed by a sweep of around 125m under a mix of commercial premises to Pearse Street which is crossed obliquely for approximately 30m. The drive continues to curve south wards passing beneath the estate of Trinity College including several educational and technical buildings for approximately 280m before a square passage of around 40m beneath a terrace of four storey commercial premises and Lenster Street South. The drive maintains a straight alignment for a 375m passage beneath the Parliament of Ireland and commercial buildings to reach St Stephen's Green at the junction with Merrion Row. On the same alignment then crosses square beneath road for 40m with a further 40m under the footway and margins of the Green to arrive at the north headwall of St Stephen's Green station box.

Table 3.12: Summary of Face Conditions Drive C8

Tara - St Stephne's Green						
Distance	Length	Face Conditions				Grade %
135	135	CLU				FLAT
227	92					T
582	355					2
630	48					T
867	237					1.25
917	50					T
987	70					FLAT

3.6.9 Section C9: St Stephen's Green to Charlemont

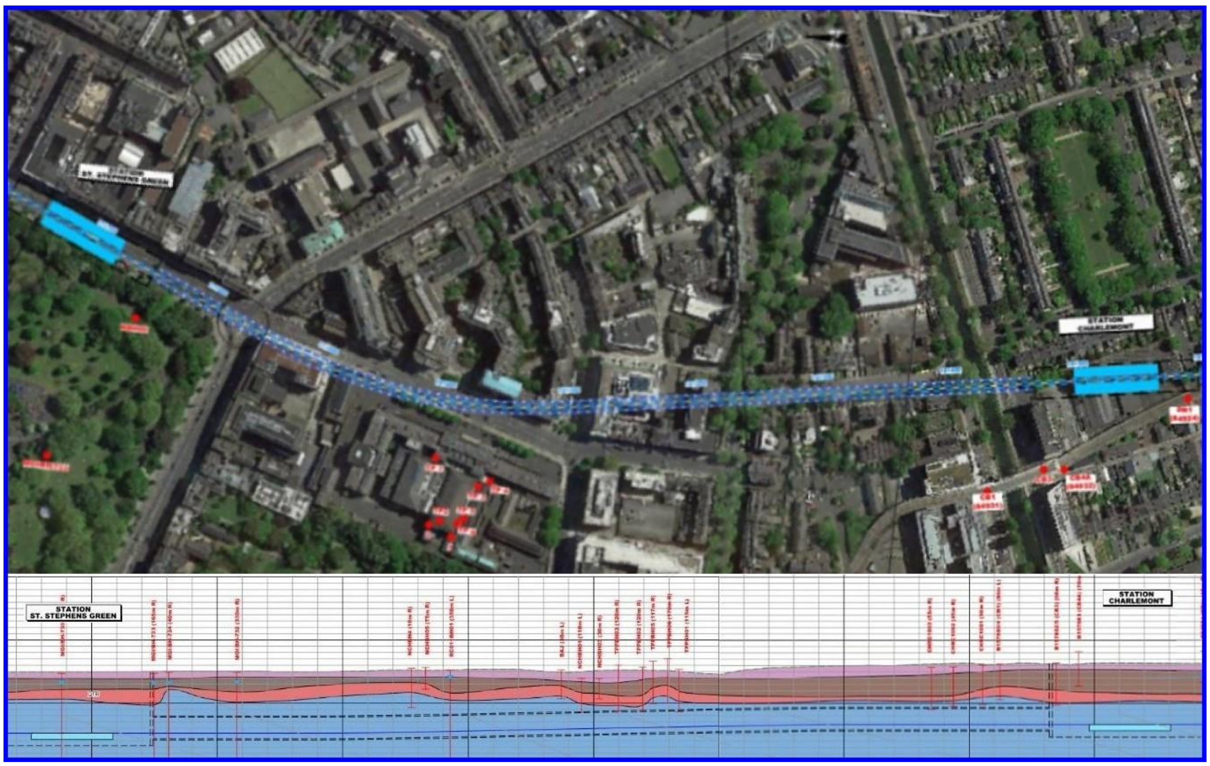


Diagram 3.14: Geologic Profile for TBM Drive C9- St Stephen's Green to Charlemont

C9 drives with a full face of CLU over its whole 710m length.

Table 3.13:Summary of face conditions Drive C9

St Stephen's Green - Charlemont				
Start	End	Length	Face	
0	710	710	CLU	

Drive C9 launches into a straight section before turning onto a curve to line up with Charlemont Station. The dive is excavated within the Argillaceous bioclastic limestone (CLU) bedrock for its full length. From the south headwall of St Stephens station box, the line of the tunnel continues along Earlsfort Terrace under a five-story office block and adjoining Edwardian terrace houses/offices.

3.6.10 Section C10: Charlemont to south of Charlemont TBM Burial Site

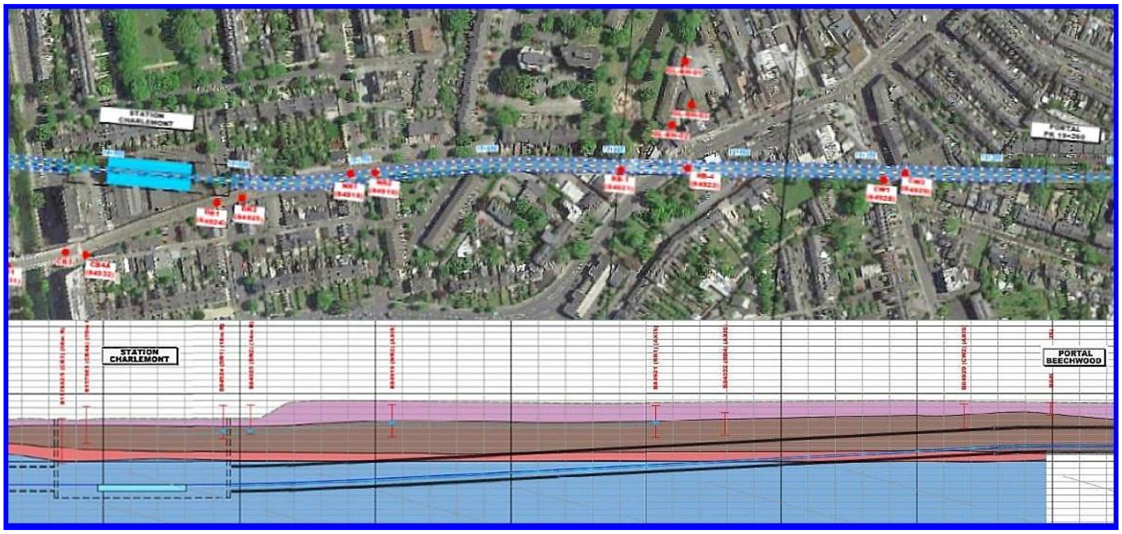


Diagram 3.15: Geologic profile for TBM drive C10- Charlemont to south of Charlemont TBM Burial Site

Table 3.14:Summary of face conditions Drive C10

Charlemont - Beechwood Portal					
Start	End	Length	Face Conditions		
0	80	80	CLU		
80	170	90	CLU	QTR	
170	420	250	CLU	QTR	QBR
420	560	140	QTR	QBR	
560	600	40	QBR		

Excavation will commence in the Argillaceous bioclastic limestone (CLU) rising through the transition rock/soil (QTR) and finishing in the Dublin Brown Boulder clay (QBR). Assets above the line of the tunnel are predominantly low-rise residential dwellings.

4. Tunnelling Strategy

4.1 Scope

MetroLink includes two main tunnels:

- Airport Tunnel: 2,084m running from Dublin Airport South Portal north to Dublin Airport North Portal; and
- City Tunnel: 9,640m running from Northwood Portal south to south of Charlemont TBM Burial Site.

4.2 Tunnel Design

- Ring internal diameter is 8.50m; and
- Segment thickness of 0.35m is assumed subject to detailed design.

The tunnel ring is assumed to be 1.80m long (along tunnel centreline). This is stated to be based on a balanced solution between the self-weight stresses, ease of handling and the performance of the TBM.

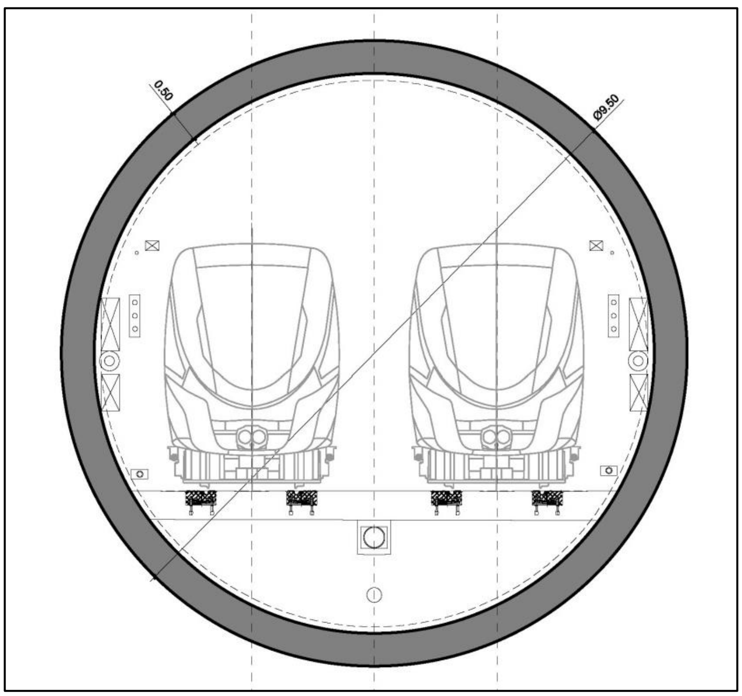


Diagram 4.1: The tunnel cross-section is shown with an internal diameter of 8.5m, and an external diameter of 9.5m

An 8.5m ID ring with 350mm segments and a 150mm thick layer of grout requires a cut diameter of around 9.5m.

However, the flexibility in ring dimensions will depend on the type of ring design adopted, the TBM design and the minimum radius on the alignment.

4.3 Tunnelling Strategy – Baseline

The ‘Baseline’ tunnelling strategy is defined as:

- Single bore twin track running tunnels (and therefore no cross-passages);
- No dividing wall between tracks;
- Two running tunnel TBMs;
- Drive 1: Dublin Airport South Portal to Dublin Airport North Portal; and
- Drive 2: Northwood Station to Charlemont Station and then on to a burial site for the TBM close to the existing Luas Green Line Ranelagh Station.

4.4 TBM Type

The running tunnels themselves are of uniform section and, given the length of the proposed Project, are suited to construction by TBM. TBMs are costly, have lengthy lead-in periods for design and manufacture, and take time to launch and recover. However, once established underground, their speed and consistency make their use the most cost-effective means of constructing long, standardised tunnels.

The use of segmental pre-cast concrete rings offers the most efficient and robust method of rapidly providing a structural lining to the tunnels in variable ground conditions. This is a well-proven form of construction for providing accurately mined and water-resisting structures for railways.

The tunnels will have an internal diameter of 8.5m, determined by the requirements for rolling stock clearance, space to locate utilities and other railway services, and emergency evacuation. The minimum curvature radius considered for the tunnel is 350m, and the bored tunnel has been designed accordingly.

A significant area of land (typically greater than 30,000m2) is required for launching and driving the machines needed to bore tunnels of this size. The proposed TBM launch sites (Dublin Airport South Portal and Northwood) both have sufficient land available.

4.4.1 Tunnel Boring Machine (TBM) Selection

The basis for the selection of the TBM should principally be the prevailing ground conditions, but it would also be informed by factors such as adaptability and robustness of the machine, suitability for minimising settlement and spoil treatment, as well as the space available for the launch site and other local variables.

4.4.2 Types of Machine

The MetroLink tunnels will be excavated through variable and water bearing ground (see Section 3). This points to the need for face support and preferably the capability to apply fluid pressure to resist hydrostatic load. There are several methods available for achieving this, namely air pressure, slurry pressure and EPB, all of which can be deployed in TBMs of various types, referred to as ‘closed-face machines’.

Closed-face TBMs, incorporating a sealed bulkhead capable of restraining the ground and/or providing a reaction for other support measures, offer the greatest security in these kinds of conditions.

The use of compressed air to improve the stability in water bearing ground, although a useful tool, has for a number of reasons been effectively superseded as a principal mechanism of face support, particularly in closed-face machines, by more sophisticated technologies. It is now largely held as a reserve measure for use in specific circumstances, such as machine head interventions, or as an ancillary component of some slurry support systems.

Of the two remaining support methods, slurry and EPB, the latter has been refined significantly in recent years and is now more prevalent in medium sized (3-7m) machines. A further option is now available, a variable density slurry TBM, which attempts to combine the best of both a slurry and an EPB TBM.

4.4.3 Earth Pressure Balance (EPB) TBM

Diagram 4.2 shows a schematic of a typical EPB machine. The soil is cut by a rotating cutterhead (1), and the cut material typically mixed with a shaving-foam-type material in the cutting chamber (2) to produce a homogeneous toothpaste-like material. This material is then removed by an Archimedean screw conveyor (5).

By varying the speed of the screw conveyor in relation to the speed of forward advance of the TBM, the pressure in the cutting chamber can be controlled. If the pressure is maintained equal to, or greater than, the groundwater pressure, then groundwater will not flow into the cutting chamber, minimising settlement and the chance of collapse.

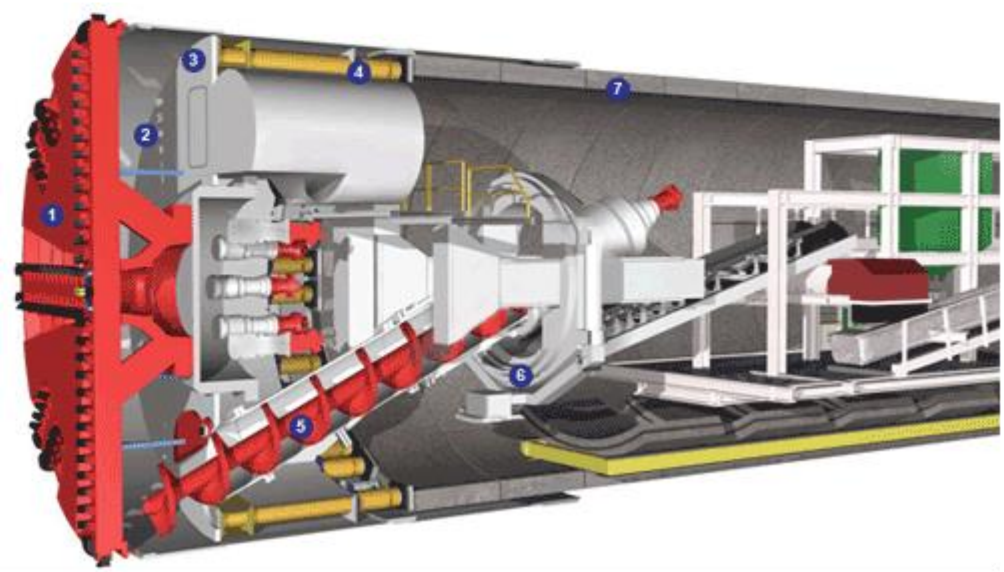


Diagram 4.2: Schematic of a typical EPB machine (from Herrenknecht)

To enable the build-up of pressure in the cutting chamber, a ‘plug’ of material is required to form in the screw, allowing the pressure to dissipate along the length of the screw. Excavated material is discharged within the machine, ready for transport to the surface and immediate removal from site if appropriate.

Through the injection of a variety of additives into the head chamber, the loosened spoil is ‘conditioned’ to a plasticised state, sometimes described as a ‘toothpaste’ in which it can be made to flow but resist the flow of water from the face. The appropriate selection and use of additive ingredients are crucial to the success of this process. However, there is a wide range of proven materials available, together with the expertise to treat and react to a wide range of ground conditions.

4.4.4 Slurry TBM

Diagram 4.3 shows a schematic of a typical slurry TBM. The principle of a slurry TBM is that a carefully formulated mud, usually based on bentonite clay and water, is continuously pumped through the bulkhead of the machine, (6), to provide a resisting pressure to ground forces. The pressure of the slurry in the cutting chamber (2) (in front of the bulkhead) is maintained at a pre-designed pressure equal to, or greater than, the groundwater pressure. This prevents groundwater and/or ground from flowing into the TBM cutting chamber, thus minimising settlement and guarding against collapse.

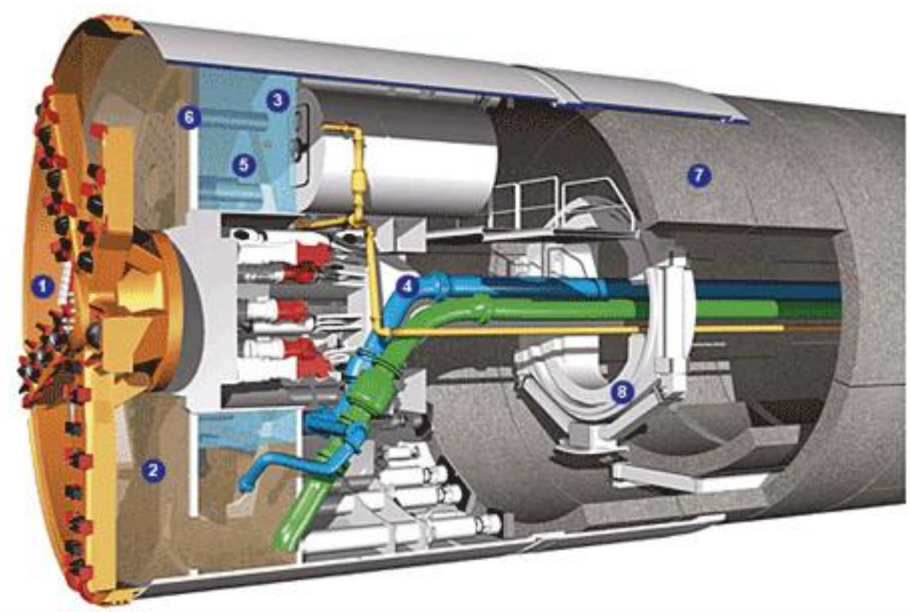


Diagram 4.3: Schematic of a typical slurry TBM

The slurry also acts as a transport medium for the material that has been excavated by the rotating head of the machine (1), and as both a coolant and a lubricant to reduce wear. In some cases, for example sandy conditions, the bentonite may 'cake' on the excavated face, forming a partial seal and reducing the ability of groundwater to flow into or out of the ground.

Excavated material and slurry are removed by the system from the base of the cutting chamber and pumped along the tunnel to the surface, where the mixture is processed in a separation plant and the excavated material extracted. The density of remaining liquid is adjusted as necessary before it is pumped back into the machine for another cycle.

Apart from the separation and treatment plants on the surface, the whole tunnelling system is effectively sealed and can be used to respond to changing ground conditions by altering the pressure applied at the face by the pumps.

A refinement of the standard slurry TBM uses a 'bubble' of compressed air, shown as (5) in Diagram 4.3. Face pressure is usually maintained and controlled very accurately by applying and adjusting the air-pressure applied to the slurry at the air-cushion.

4.4.5 Comparison between EPB TBM and Slurry TBM

An EPB TBM has many advantages over a slurry TBM:

- EPB TBMs are less complex, and therefore less expensive. Less complex also means quicker to design, manufacture, erect and dismantle;
- A slurry TBM also requires a separation plant on surface, which is more expensive to purchase, erect and operate than an equivalent conveyor system for an EPB TBM;
- The speed of tunnelling for an EPB TBM is limited by the speed in which it can safely cut the ground and by the capacity of the logistics supply. A slurry TBM has the same constraints but is also limited by the capacity of the slurry pumps and the treatment plant;
- Since the system relies on fluidised spoil transport, a slurry TBM can only ever be operated in closed mode. If the screw conveyor on an EPB TBM is increased such that the material is removed faster than it is excavated, then the TBM is effectively operated in 'open mode'. Whilst this provides less protection against settlement and collapse, in the right ground conditions, this can increase the tunnelling speed;
- The need to separate and treat material on the surface requires an adequately sized site to allow for spoil disposal;
- If the excavated material is composed of a significant proportion of clay sized particles, these can prove difficult to separate out from the bentonite transport medium. Processing times can be longer than the cycle time of the TBM, leading to a back log requiring extended hours of operation or passive separation in settlement lagoons; and
- The high level of sophistication incorporated in the slurry TBM requires a greater degree of informed management and control and makes the system more expensive than equivalent technologies. It is also very sensitive to the effectiveness of the maintenance regime.

However, whilst there is an overlap in operability, the two types of closed-face TBM are best suited to very different ground conditions.

An EPB TBM relies on the conditioning of mined material in the head of the TBM, and providing this conditioning is undertaken by personnel with the requisite skills and experience, the technique can be used to control the ground across a wide variety of conditions, including those not requiring active support pressure. However, in order to facilitate the forming of a pressure-retaining 'plug' in the screw conveyor, without the need for excessive quantities of conditioning agents, a relatively high percentage of fine material should be present. Therefore, an EBM TBM is particularly well suited to cohesive clays, silts and fine sands.

A slurry TBM uses a manufactured slurry to support the uncut ground and, as such, does not require any particular properties from the ground. However, when it comes to separating the excavated ground from the slurry, fine material is extremely difficult to extract from the slurry, resulting in significant restrictions on the tunnelling rate if the separation plant is undersized. Therefore, slurry TBMs are more suited to cohesionless, coarser-grained sands and gravels.

The difference is shown graphically in Diagram 4.4.

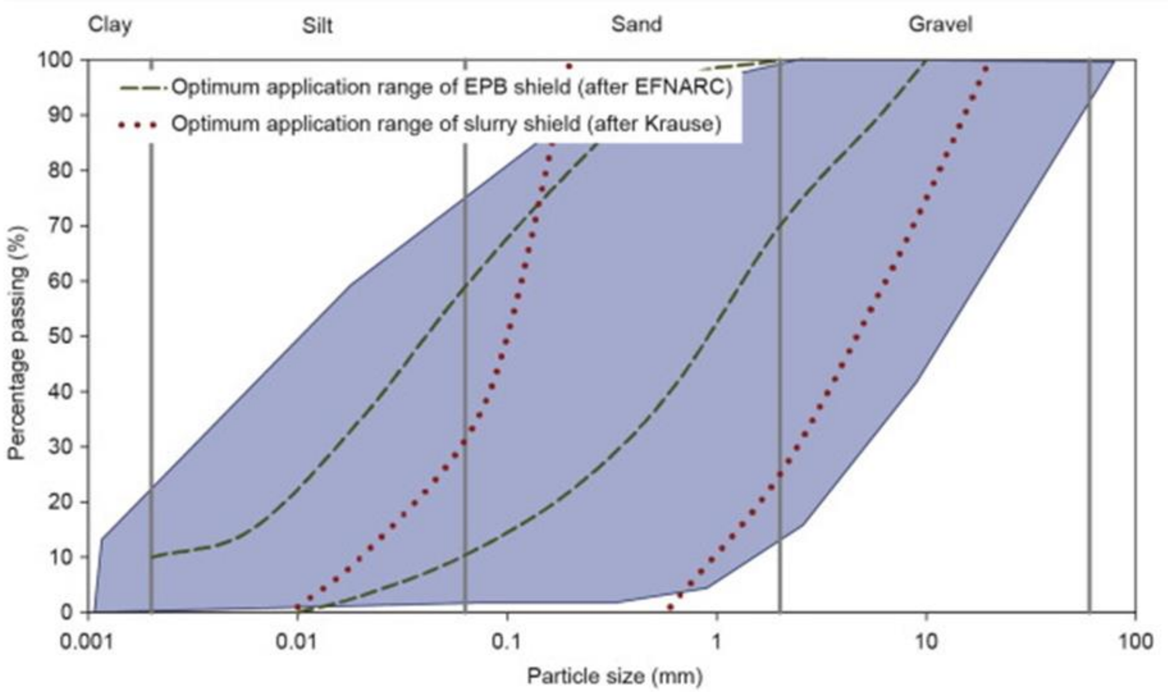


Diagram 4.4: Applicable particle sizes for the TBM types from Mechanised Tunnelling in Soft Soils (Zumsteg and Langmaack, 2017)

Table 4.1 Comparisons between EPB and Slurry machines

Slurry TBM Disadvantages	EPB TBM Disadvantages
▪ More complicated system to operate and maintain ▪ Requires extensive addition of materials ▪ Requires a sophisticated slurry separation plant ▪ Cannot take advantage of self-supporting ground (i.e. no open mode) ▪ Requires a large work site ▪ Higher capital costs ▪ Higher power requirement	▪ Face pressure must be calculated in advance of tunnelling ▪ Requires higher torque ▪ Needs greater cutterhead power ▪ Muck is exposed in tunnel including any contaminated spoil ▪ Successful EPB tunnelling and face control is largely dependent upon the skill and diligence of the operator ▪ EPBs are prone to much higher wear compared to slurry

SLURRY TBM Advantages	EPB TBM Advantages
▪ Required pressure is determined/controlled by system ▪ Lower torque ▪ Lower cutterhead power ▪ Contaminated muck not exposed until it reaches the surface ▪ Able to integrate rock crusher ▪ Cleaner tunnel environment	▪ Overall simpler system to operate and maintain ▪ Muck is immediately ready for disposal ▪ Able to take advantages of self-supporting ground (i.e. open mode) ▪ Better overall production rates are possible ▪ Lower capital cost ▪ Smaller site and launch shaft

Table 4.2 Comparisons between EPB and Slurry Machine

EPB TBM	Slurry TBM	EPB TBM + Additives	Slurry TBM + Additives	Ground Type	Grain Size Range
✓		✓	✓	Clay	<0.002mm
✓		✓	✓	Silty Clay	<0.002mm and 0.002–0.06mm
✓	✓	✓	✓	Silt	0.002–0.06mm
✓	✓	✓	✓	Silty Sand	0.002–0.06mm and 0.06–2.0mm
	✓	✓	✓	Sand	0.06–2.0mm
		✓	✓*	Gravel	2.0–60mm
*If permeability (k) is greater than 10^{-4}cm/s then slurry and additives are not sufficient					

The anticipated geology in Dublin does not fit smoothly into the target range for either of the machine types:

- Excavation through limestone could cause difficulties with a slurry TBM if the separation plant struggled to keep up with the TBM.
- When excavating through the sands and gravels that are likely to be encountered between Glasnevin and O'Connell Street Stations, an EPB TBM may struggle to maintain an even cutting chamber pressure or maintain a plug in the screw which is a fundamental requirement for face control.

4.4.6 Variable Density Slurry TBMs

There is, however, one further type of TBM and that is a variable density slurry TBM. This is effectively a multi-mode machine, which allows:

- Open mode, with the cut ground removed by the screw conveyor operating at high speed, and discharging onto the belt conveyor for transport to the tunnelling site;
- EPB mode, with the cut ground removed by the screw conveyor operating at low speed;
- Slurry mode, with the cut ground removed within a slurry, and the pressure in the cutting chamber maintained by an air bubble; and
- High-density slurry, with the cut ground removed by the screw conveyor.

When operating in high-density slurry mode, there is a much greater resistance to the loss of slurry into the face through cracks, fissures and voids, and by using the air bubble, a much more precise control over the pressure in the cutting chamber is possible. It is also possible to maintain a greater range of pressure from the tunnel crown to the invert, which can match more closely the in-situ conditions.

It is not possible to maintain a high-density slurry like this in a standard slurry TBM, as the pumps would not be able to pump a high-density fluid without excessive wear. In a variable density slurry TBM, the high pressure is held by the screw conveyor which discharges into the slurry circuit, where it is diluted and transported to surface. Hence, by combining the two technologies (EPB and slurry), the resulting TBM is able not just to perform the functions of each, but to gain an additional mode which is greater than either technology can achieve on its own.

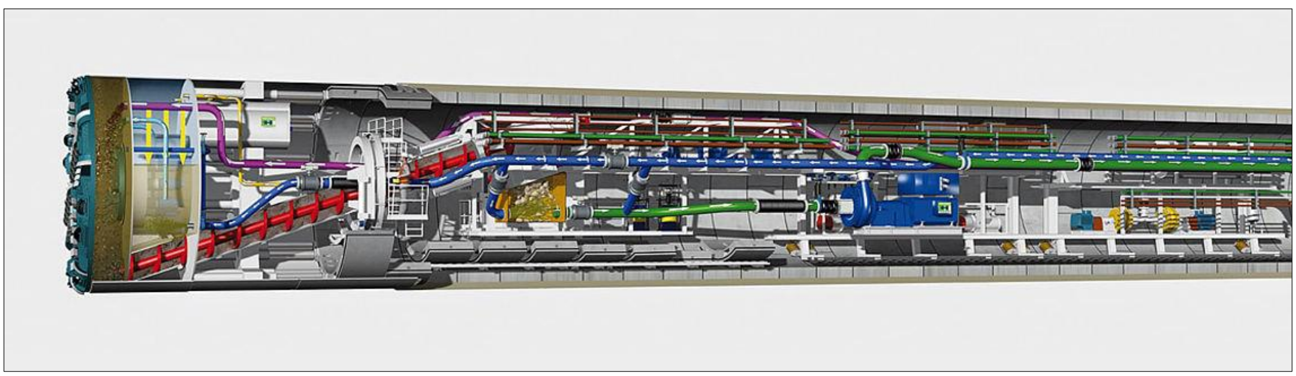


Diagram 4.5: Variable density slurry TBM (from Herrenknecht)

4.4.7 Recommended TBM

On the basis of the currently available geotechnical conditions, and the constraints on tunnel size, depth, alignment and drive direction (all discussed separately in this report), whilst EPB and slurry TBMs could be utilised, it is recommended that a variable density slurry TBM be specified for the City Tunnel south from Northwood.

A variable density slurry TBM is the preferred option for the Airport Tunnel too.

A detailed specification for the TBMs should be developed by the Contractor(s) and the selected Contractor(s) will procure the TBM based on this specification. The use of a Variable Density TBM is not mandated. This specification would set out the features and facilities required, and the performance expected taking full account of the ground conditions and constraints identified. It would also assist in the risk management of the tunnelling works.

4.5 Spoil Treatment

4.5.1 Earth Pressure Balance Machines

As described above, in order to create a positive face pressure in an EPB TBM, foam conditioning additives are mixed with the excavated spoil at the cutterhead to create a plasticised, homogeneous and impermeable soil paste.

The spoil is then removed from the machine to the surface by conveyor belt and then by lorry to a designated tip site. The spoil is classified as non-hazardous. The additives remain mixed in with the excavated spoil and are not separated out but are highly biodegradable. They do not present any environmental hazard, and no treatment plant is required for this material. However, due the nature of the conditioned spoil, it is sometimes necessary to contain the spoil in a bunded area to allow the foaming agent to degrade.

The foam is created in foam generators located on the TBM close to the front of the machine. The generators are high-speed mixing pumps which blend the foaming agent with water to make a dense foam not dissimilar to shaving foam. The foam is mixed with the spoil by injecting through ports in the spoil chamber behind the cutterhead and directly onto the face via ports on the rotating head. Fixed mixing arms welded to the bulkhead ensure that the foam is well mixed with the spoil before it is extracted via the screw conveyor. The spoil can be handled by conveyor belts both horizontally and by high angle (vertical) conveyors.

4.5.2 Slurry Machines

With slurry machines, bentonite slurry is mixed with the excavated spoil in the head of the TBM. The spoil and bentonite mixture is removed from the head and is then pumped back along the tunnel to the surface where the bentonite fluid is separated from the excavated material. The bentonite slurry is recycled and pumped back into the tunnel for re-use while the excavated material is loaded into lorries and taken to a designated tip site. The separation of the excavated material from the bentonite slurry is described in detail below.

Separation is the process of removing the solid excavated material from the bentonite slurry that has been used to transport the excavated material from the TBM to the surface.

Separation takes place in several stages, dependent on the granular size of the loose spoil material and is based on mechanically generated centrifugal forces, filter presses and screening technology. Modern screening technology includes hydro-vacuum cyclones, vertical separators and centrifuges to form a closed recycling concept and ensure that the critical fine particles are removed.

Several proprietary makes of separation plant are available on the market. Diagram 4.6 shows a typical treatment plant of about the size that would be necessary to be able to support a TBM of around 9.5m cut diameter augmented by holding tanks and filter presses as needed. All treatment plants employ similar principles for separation but vary in size depending on the size and anticipate speed of the TBM, and the numbers and sizes of the plant for each stage will depend on the anticipated ground conditions.

Diagram 4.6: A Typical Slurry Treatment Plant

The bentonite suspension (bentonite and excavated material) is first passed over a series of coarse vibrating screens to remove large solids, typically greater than 5mm. The oversize material (tunnel spoil – rock and gravel) from the screening process is then moved to a spoil storage heap by conveyor, from where it is then loaded into road-going tipper wagons and taken away to the final disposal site.

The bentonite suspension which passes through the screen is then further treated to remove smaller material (sand) from the suspension. This is achieved by the bentonite suspension being pumped to a set of main hydro cyclones (typically 250mm to 450mm diameter) where suspended solids, down to the size of fine sand, are concentrated and discharged as the underflow onto a vibrating dewatering screen. This screen effectively dries the sand, which is then discharged onto the spoil heap.

The remaining fluid is then pumped into secondary, smaller hydro cyclones, which concentrate the course silt particles in the fluid and discharge them onto the sand bed on the dewatering screen. The size of the hydro cyclone dictates both the flow capacity and the size of the solids it is able to remove. The smaller the hydro cyclone, the lower its flow capacity, but the smaller the particle size it can remove.

The bentonite slurry which overflows from the hydro cyclones contains a much lower concentration of suspended solids than the feed material and may be sufficiently clean to be re-used after passing through the hydro cyclones only once. However, as the quantity of the suspended solids in the feed material increases and the viscosity of the fluid increases, the ability of the hydro cyclones to clean the slurry reduces, and it may therefore be necessary to circulate the slurry two or three times through the de-sander before it is sufficiently clean to be re-used.

After de-sanding, the slurry may still contain silt and clay size soil particles which may inhibit the ability of the bentonite slurry to fulfil its function of transporting material. To remove the fine particles, the slurry can be passed through a de-silter or centrifuge. Fully cleaned slurry material can then generally be returned to the system and stored, before being pumped back down to the TBM. If very fine particles are present, as would be the case for clay and limestone, these are separated out from the slurry using firstly flocculation to thicken the slurry, followed belt filtration, with the concentrated slurry placed between two very fine filters and squeezed.

The slurry from the TBM is pumped to surface and into large storage tanks, which are agitated to avoid separation. Following treatment, the slurry is pumped to further storage tanks to wait until required by the TBM. Therefore, the separation plant is slightly removed from the TBM, and the separation plant operates the whole time, and not simply during the TBM excavation.

Bentonite slurry can be re-used repeatedly provided its properties are carefully monitored and kept under control. Fresh bentonite is introduced as required, with dry powder delivered to site in a tanker, mixed with water, and stored in agitated tanks until required.

The plant is often housed in an acoustically clad steel-frame building to contain the noise from the separation process.

On completion of all tunnelling works, the bentonite slurry used for providing support and transport would need to be disposed of to a designated tip site. Under Irish regulations, it is classified as a non–hazardous waste. This means that it can be placed in an approved landfill tip with transportation by a licensed carrier.

4.6 Tunnel Segment Production

It is assumed that the pre-cast concrete tunnel segments are manufactured in a specialist facility off site and transported to site by HGVs, where they will be stored at the Northwood Construction Compound.

The segments will be manufactured and tested in accordance with the British Tunnelling Society (BTS) Tunnelling Specification. This defines tight tolerances for segment moulds and the segments themselves. The concrete mix is assumed to contain polypropylene fibres as fire protection and steel fibres instead of rebar reinforcement.

Periodic 3D-scanning of segments and made-up moulds will be required, searchable records must be maintained of all checks and measurements at all stages of the manufacturing process, and full traceability of the constituent parts will be required.

Segment production should provide at least three months' stock at the predicted production rates prior to TBM launch. Ideally, a minimum of seven day's supply should be able to be stored on site, and the launch site areas detailed below take this into account.

4.7 Connecting Tunnels

In addition to the two running tunnel sections described in this report, there are a number of other tunnels required for MetroLink. These are:

- Two tunnels are to run parallel to the main tunnel from the Dublin Airport South Portal:
    - The 5.65m ID Ventilation tunnel which runs for approximately 550m, after which it connects to the main tunnel; and
    - The Access tunnel which runs for approximately 350m, after which it connects to the main tunnel. This tunnel could be smaller than the Ventilation tunnel, but it is likely to be driven using the same TBM.
    - These tunnels are likely to be built using a closed-face TBM, with SCL techniques used for the running tunnel connections.
- Two connection tunnels from the shaft at Albert College Park to the main (running tunnel). These are proposed as SCL tunnels; and
    - A single Evacuation and Ventilation tunnel from the south of Charlemont Station to the main (running tunnel). It is proposed that this tunnel be constructed using SCL techniques. SCL techniques are discussed in Section 4.8.

4.8 Low Point Sump

There are two low point sumps in the Airport Tunnel, but none in the City Tunnel (where the low points are within stations).

The low point sump passages will be constructed using SCL techniques from the main tunnel after the TBM has finished. The sequence of works will be:

- Install survey monitoring points in the main tunnel;
- Divert any in tunnel services;
- Install de-pressurisation wells or grouting, if required;
- Install props, if required;
- Pull or break out top section of tunnel lining rings;
- Excavate top heading of 1st advance of passage;
- Spray shotcrete to support top heading;
- Pull or break out lower section of tunnel rings;
- Excavate and shotcrete bottom section;
- Continue advancing passage until end chainage; and
- Sink low point sump.

Prior to any works on the low point sump passage, monitoring points will be established in the main tunnel and background readings taken to establish baseline values. These monitoring points will be surveyed daily while the works are carried out to ensure no movement in the main tunnel. The monitoring points could be installed shortly after the TBM passes, which would give plenty of time to obtain a stable baseline.

Any services that will still be required will be diverted around the proposed opening before breaking out the tunnel rings and excavating the initial advances of the eye of the passage.

If required, de-pressurisation wells will be installed through the tunnel rings below and to the side of the low point sump passage.

The top section of the passage will be excavated and shotcrete applied before the lower section of tunnel rings are broken out. The passage will then be advanced by top heading and invert to the location of the sump in advances typically 1m to 1.3m long. All inverts will be closed with sprayed concrete to provide a stable tunnel.

Once the passage is at the end chainage, a timber shutter will be set up and a reinforced concrete slab cast, with the profile of the sump shaft boxed out. Once cured, the concrete invert will be broken out and the first advance of the shaft will be excavated and sprayed.

The sump will be sunk one advance at a time, again usually 1m, until the sump is at the final depth. A base slab will be installed, and reinforced concrete works will complete the sump and passage.

All SCL works will be controlled by a Required Excavation and Support Sheet (RESS) which will be produced by a Senior SCL Engineer. The RESS sets out the actions required for the tunnel to advance, from the installation of monitoring points to the thickness of the sprayed concrete. The RESS is produced after a daily review meeting which looks at the survey monitoring data, ground conditions, as-constructed drawings and production. Without a RESS in place, no SCL works will be allowed.

Diagram 4.7: Example of Excavation of a Low Point Sump (A3, Hindhead Tunnel, Surrey)

Diagram 4.8: Break out of a Passage from a Main Tunnel

4.9 TBM Delivery and Assembly

The delivery method for the TBM will depend on where the chosen manufacture is located, however it is assumed that the TBMs will be delivered via barge/ship to Dublin and then by road to the work site.

TBMs are usually comprised of the following sections: cutterhead, front shield, middle shield, tail shield and towed gantries.

The cutterhead is fixed to a drive module in the front shield which provides the turning force to rotate the head. The middle shield contains the shove rams. The tail shield is where the segmental lining is built and contains grout tubes for filling the annulus between the lining and cut ground.

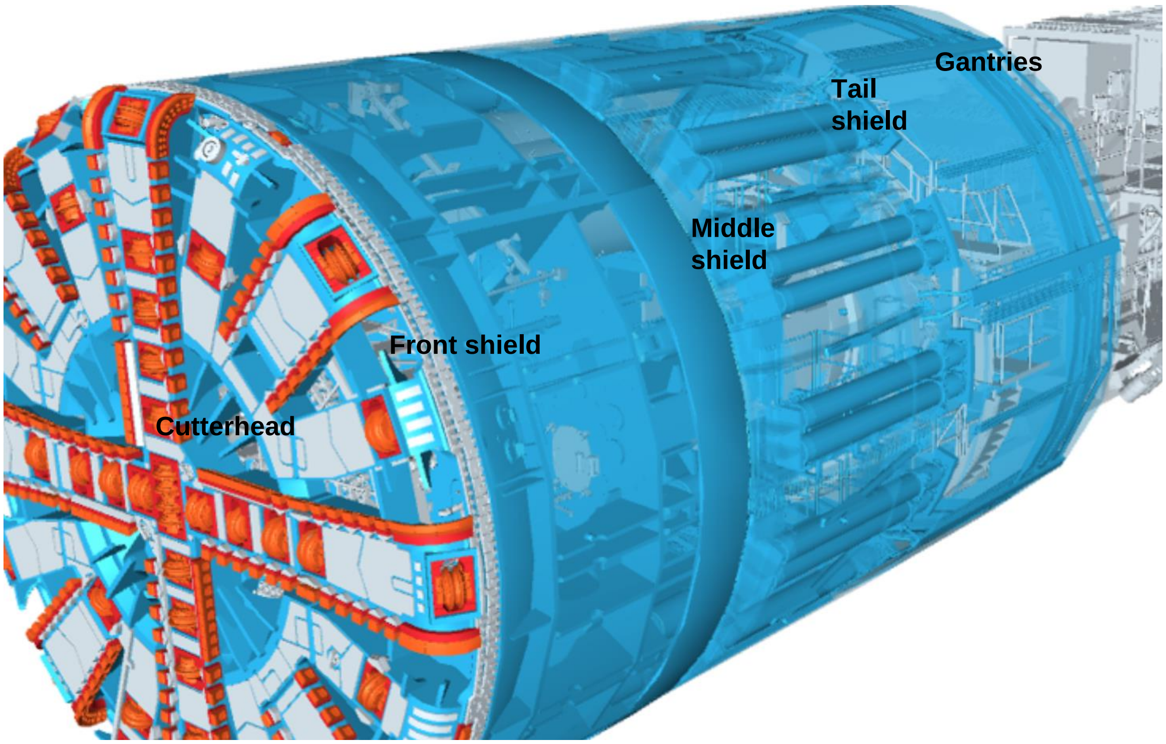


Diagram 4.9: Cutterhead, front, middle and tail shields of a TBM

The assembly of the TBM will involve the use of cranes to lift and position components, mobile elevated working platforms to provide access, telehandlers for delivering smaller components, generators, welding sets, lighting sets, small tools and other conventional plant such as road-going lorries and vans.

The cutterhead will be delivered in sections to suit delivery route and will be welded together on site. This is usually done under a scaffold cover to protect the head and provide shelter for the welders carrying out the continuous welding.

Diagram 4.10: Three-piece Cutterhead in a Barge

The front, middle and tail shield are often constructed in two halves: a top and a bottom. This allows for the section to be turned through 90 degrees when loaded onto delivery lorries to maintain a manageable width. Early design of the TBM will need to include the delivery route to enable the designers to produce shield sections that can be delivered to site. Due to the size of the TBMs for MetroLink, it is expected that the TBM will be manufactured in four roughly equal sections, an invert, two sides and a crown, similar to that shown in Diagram 4.14.

During the Factory Acceptance Tests, the TBM sections are bolted together, but when assembled on site, the sections are bolted and then welded on the outside. This requires scaffold structures to access the welding areas and allows for screening and weather proofing, reducing the environmental impact on any local receptors.

Diagram 4.11: Bottom half of the front shield of a two-part machine in the factory

Diagram 4.12: TBM Shield in Multiple Pieces

Prior to delivery, laydown areas are set up on site with support cradles (see Diagram 4.16) ready to be loaded with the bottom halves of the TBM shield. Each of the shield sections will have had as many as possible of its components, for example shove rams, installed at the factory to minimise work on site. A crawler crane can be used to assemble the component pieces, see Diagram 4.17.

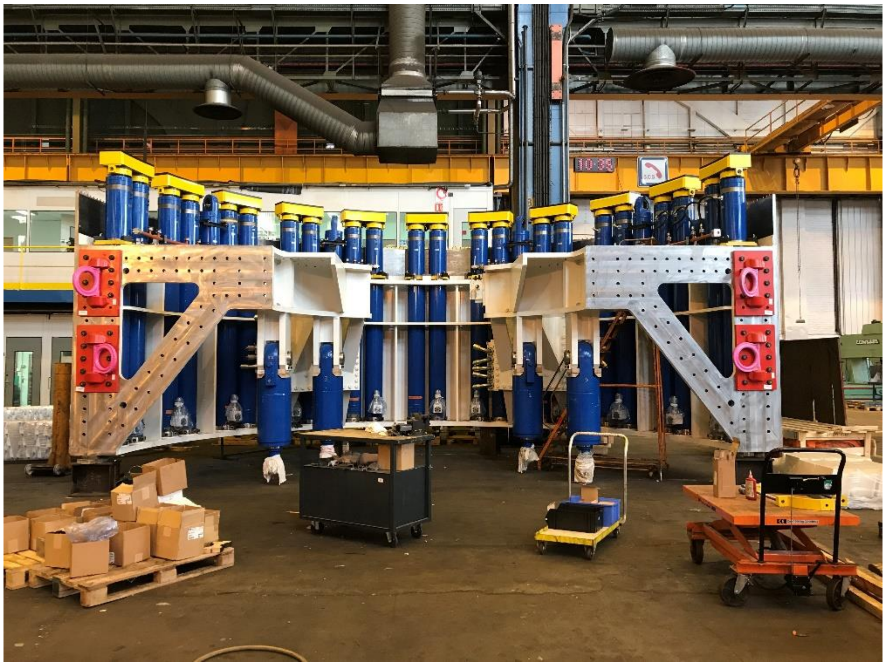


Diagram 4.13: A section of TBM shield shove rams installed in the factory

Diagram 4.14: Front and middle shield bottom halves

Note that these figures show a two-part Thames Tideway TBM being assembled on the surface, but the sequence will be the same for a four-part TBM. For MetroLink, the assembly will be in an open cut box/retaining structure.

Diagram 4.15: Drive module being lifted into place by a crawler crane

Diagram 4.16: Front shield top half being lifted into place over the now-installed drive module

Once the front and middle shields are complete, the screw conveyor and segment erector can be installed followed by the tail shield.

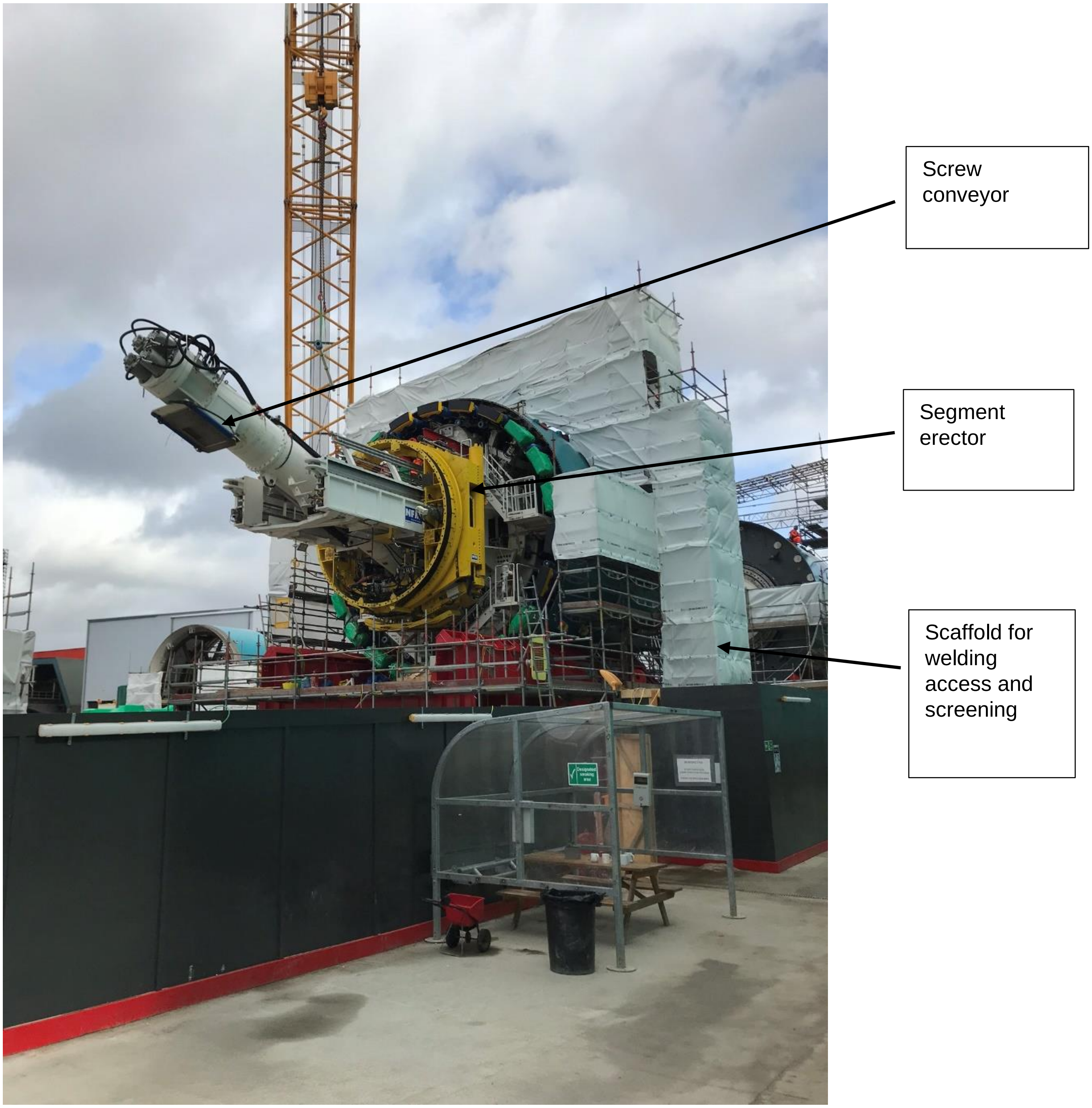


Diagram 4.17: Segment erector and screw conveyor installed

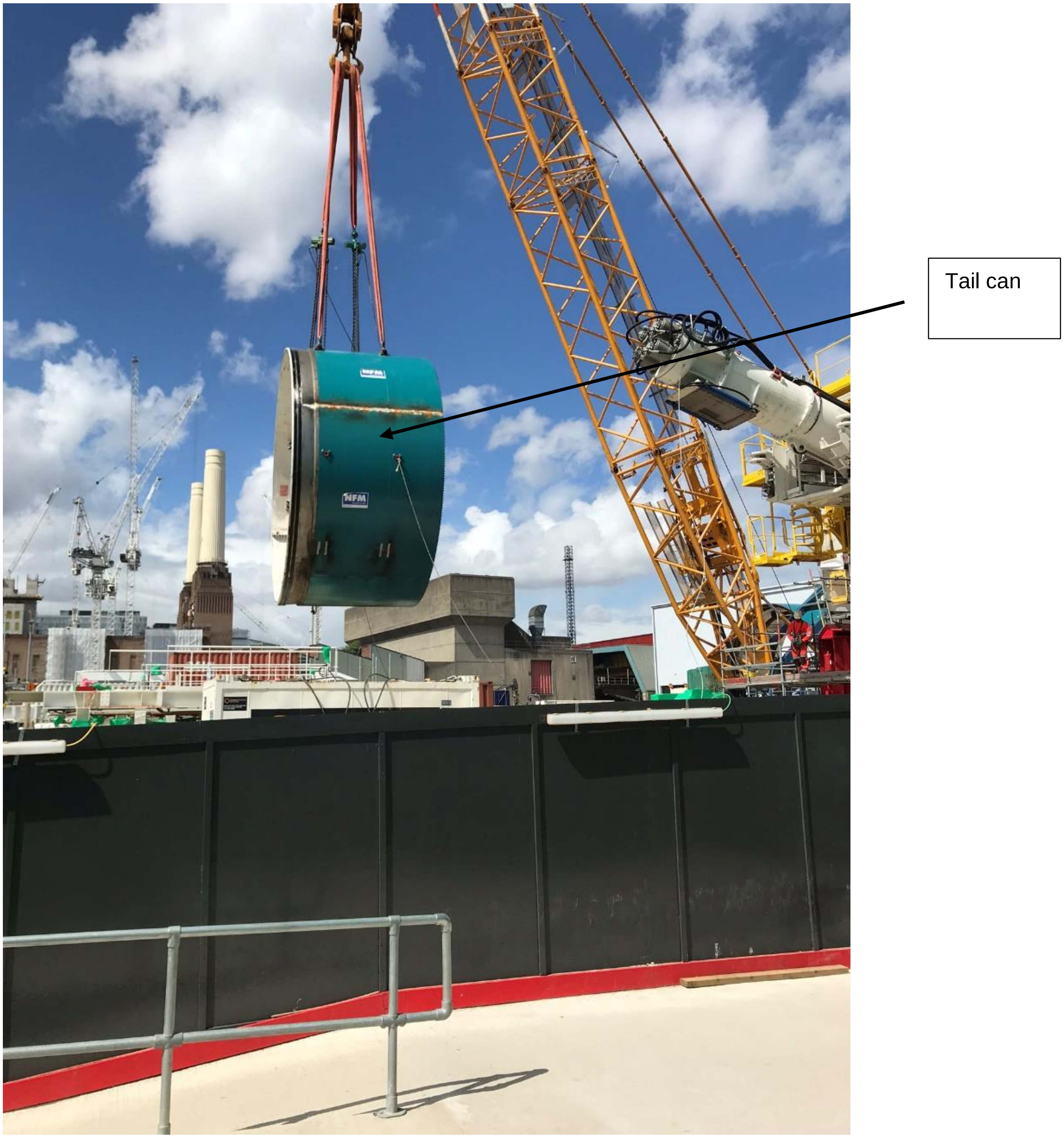


Diagram 4.18:Tail shield being lifted into place. Note: it needs to turn 180 degrees before fitting to the middle shield

Back up gantries are assembled in the factory, and all component parts, pumps, electrical controls, transformers and compressors., are installed. Following the Factory Acceptance Tests, the gantries are 'flat packed' where possible with their components, ready for delivery to site, usually on road-going lorries, where they will be offloaded and stored ready to assemble.

Diagram 4.19: TBM and gantries in factory ready for Factory Acceptance Tests

The two main drives from Northwood Portal and Dublin Airport South Portal will start from open cut boxes in which the TBMs will be assembled. The constraints of the sites mean that the boxes will be shorter than the fully assembled TBMs with back up gantries. The shield sections will be built up inside the box as described here and enough gantries installed for 'short mode' tunnelling, enough services to allow for the launch of the machine but at a much slower rate. As the TBM advances, the remaining gantries are installed until the machine is fully assembled and ready to start tunnelling at optimal advance rates. The design of the TBM gantries will be undertaken with the knowledge that a short mode launch will be required.

4.9.1 TBM Recovery and Burial

Following the completion of the two tunnel works:

- The Central Section TBM (Airport drive) will mine into the Dublin Airport North Portal (Naul Road) structure, where it will be dismantled and removed from site; and
- The Southern Section TBM (City drive), after passing through Charlemont Station and continuing south to construct the over-run, cross-over and turnback tunnel, will be driven off-line south of Charlemont Station and buried.

4.9.2 TBM Removal

The Airport Tunnel TBM will break through into Dublin Airport North Portal (Naul Road), be dismantled and then transported off site.

Pieces will be split, lifted and taken off-site in sections. Piece sizes will be as large as possible (to minimise the works on site) but must be suitable for transport to the final destination.

Sections must be thoroughly cleaned of grease, oil and dirt before loading onto transport, with these works carried out in a purpose-built 'cleaning bay' from which drainage water will be collected and passed through a silt buster treatment plant (or similar) and an oil interceptor.

4.9.3 TBM Burial

It is important to note that the quantity of TBM left in the ground is relatively small; the vast majority of the TBM is still dismantled and removed from the tunnel. Those parts that are left require thorough cleaning and are then encased in concrete.

The process starts with the completion of the tunnel and then turning the TBM sharply to the side so that it drives off to the side.

Once the TBM has built and grouted the last ring, the TBM grouting system will be modified by adding additional pipes to pump grout into the cutterhead and around the shield. At the same time, temporary power and ventilation will be installed to the back of the gantries. The main electrical power can then be disconnected, and cable and service pipes can be removed from the tunnel wall. All pipes will need to be blown clean before removal to ensure they are easier to handle and to prevent slurry spillage in the tunnel invert. A specialist flatbed rail bogie may be required to safely handle the pipes. High voltage cables will be rolled onto drums using the reverse of the process to install them. Communication and low voltage cables will be left in place until the work is complete.

All pipelines, for example tail seal grease, main bearing grease, water lines, grout lines and foam lines on the backup gantries, will need to be blown out to clean any material from them. Hydraulic connections will be blanked off after pumping the oil into tanks for removal from the tunnel. The gantries can then be split and each one towed back to the portal where it can be lifted out.

After all gantries have been removed, the main section of the TBM shield can be dismantled. This will require detailed planning to ensure that heavy items such as the erector and shove rams can be safely lifted off the TBM and removed. Hydraulic oil will be pumped from all the rams, including those on the erector, into tanks which will be taken to the portal. Electric drive motors, electrical switches, cables, grout lines, grease lines and all hydraulic hoses will be removed from the machine and loaded onto flat beds for transport to the portal. Any valves that can be removed will be taken off at this stage as well.

With all the major and minor parts removed, the TBM will be de-greased and cleaned with all de-greaser solution contained and pumped into bunded containers. Following final checks, the TBM will be signed off as ready to be concreted. A bulkhead with concrete injection ports and breather pipes will be assembled as per a temporary works design. Concrete will be pumped into the chamber and air will be displaced through the breather pipes. Once concrete is seen flowing from the breathers, concreting will stop with the TBM now encased in concrete.

5. Tunnelling Operations

5.1 Ground Movement and Vibration

A Settlement Assessment has been undertaken to determine the potential impacts that construction of the proposed Project will have on sensitive receptors such as buildings and infrastructure from the advance of the TBM. The Settlement Assessment methodology is summarised in Chapter 20 (Soils & Geology) of this EIAR.

Where necessary properties along the alignment will have pre-construction condition surveys carried out before the construction works, and where appropriate, these will be repeated after construction in order to identify any potential damage resulting from settlement and/or vibration. Extensive settlement and vibration monitoring will be undertaken along the alignment during the advancement of the TBM in order to ensure that settlement caused by the TBM is below trigger values.

Ground movement monitoring will mostly be carried out on the street, but there will be a requirement to access private property at times for:

- Building condition surveys;
- Installation of monitoring points that can be read from the street (levelling points); and
- Establishing, reading, and removing stand-alone monitoring systems (e.g. remote monitoring by Automated Total Station (ATS)).

Where assessment predicts an unacceptable risk of damage, mitigation will be taken. Mitigation measures required to mitigate any settlement are described in Chapter 20 (Soils & Geology). Such measures could include:

- Diversion or strengthening of utilities – see Section 5.2;
- Structural support to mitigate against damage, including:
    - Steel frames to support structures;
    - Tie rods; and
    - Underpinning.
- Ground treatment, providing additional support to the structure or a part of it; and
- Compensation grouting; consisting of the installation of a horizontal fan of grouting tubes drilled at a particular level (at least 3m above the tunnel crown, and at least 3m below the structure being protected). As excavation of the tunnel takes place below the fan, grout is injected into the correct location to compensate for any loss of ground during tunnelling, with the intention of keeping the structure or ground surface at or close to its original position.
- Bridge bearing survey and adjustment

A Property Owner Protection Scheme (POPS) will be put in place by TII prior to works commencing on site. This will involve advance condition surveys prior to construction for all properties within the zone of influence. Furthermore, if deemed necessary, surveys will be taken during and after the completion of the proposed Project. If it is determined that any reported minor cosmetic damage has been caused by construction of the proposed

Project, suitable remedial works will be undertaken to repair the damage to the properties with the use of the appropriate conservation technique.

Building and structure mitigation proposals based on the assessments undertaken to date are identified in Appendix 5.17 Building Damage Assessment Report..

5.2 Utilities

The findings of an initial settlement study showed that approximately 70% of utilities should not require any mitigation works, other than normal settlement monitoring to ensure that the tunnel boring and other excavations are operating within their predicted settlement limits.

The utility type most impacted by settlement was brick which is typically used for sewer construction. Brickwork is a brittle substance and may crack at the mortar joints when subjected to settlement. Such cracks are easily repaired following cessation of movement. However, if the cracking exceeds 3mm some form of internal temporary support may be needed to keep the structure in place. Any cracks can then be repaired following cessation of ground movements.

Further settlement analysis will be carried out on potentially affected utilities at the detailed design stage. Proposals for monitoring, strengthening works and possible renewal of sections of pipelines will be discussed and agreed with each of the utility companies.

Assessments will need to take into account, the utility type, material, age, condition, and an estimate of the degree of movement the that the utility has already been subjected to, along with the predated settlement (both magnitude and angle of distortion). Where damage or failure is predicted, a mitigation plan must be produced detailing the proposed actions, which will generally be to divert or strengthen. Wherever possible, these actions should be carried out alongside the other utility diversion works required for the proposed Project.

5.3 Not Used

5.4 TBM Maintenance Interventions

The TBM progresses by using a rotating cutting wheel to cut the ground. This may be equipped with 'rollers' (cutter discs), or 'scrapers' (cutting teeth) which burst or grind off the ground, shaving off perhaps 10 or 20mm per rotation. As the tunnel progresses, the cutting discs and teeth can be worn or damaged and require replacement. Replacement of these parts is achieved from within the cutting chamber in front of the pressure bulkhead.

As described in Section 4.4, it is the pressure in the cutting chamber that prevents groundwater (and accompanying ground) from flowing into the cutting chamber.

The stopping of the TBM for inspection and changing of the discs or teeth is often referred to as an 'intervention', and there are two types:

- 'Free air': where the ground is stable and groundwater flows slow or absent, the cutting chamber is fully or partially emptied. The door to the cutting chamber is then opened and entry by the work gang is possible; and

- 'Compressed air': where air pressure in the cutting chamber is required to resist the inflow of groundwater and / or ground into the chamber. The cutting chamber is partially emptied, and compressed air introduced to maintain the required pressure. The work team can now gain access through an airlock in which they are themselves pressurised. In completion, the work team exit via the airlock where they are gradually depressurised.

Compressed air interventions need to be very carefully controlled to ensure the safety and health of the work teams. Therefore, they are to be avoided where possible.

One further option exists: to change the discs and / or teeth when they can be exposed from the front, as is the case when the TBM passes through a station or adjacent to a shaft.

An Intervention Strategy will be written, defining where interventions may and may not take place, and where planned interventions will take place. The TBMs and the site will be equipped with the necessary equipment, the necessary specialists employed, and the required training, medicals and testing will be carried out, to enable the use of compressed air interventions. However, with stations at regular intervals, these will the primary location for interventions.

The intervention strategy will define the predefined 'fixed' locations for cutterhead interventions and provide the necessary information for unplanned interventions in the event that these are required. This will include:

- Any areas where interventions are prohibited (i.e. beneath sensitive structures); and
- A plan for 'possible interventions' including, for defined zones:
    - The approval process required;
    - The required compressed air pressure for any intervention; and
    - Locations where permeation grouting or other ground treatment or replacement from surface may be necessary to provide a secure working area (safe haven).

5.5 Tunnel Clean Out

On completion of the Airport Tunnel, the tunnel will be cleaned out, working from the DANP back to the DASP.

On completion of the City Tunnel, it is proposed that the tunnel will be cleaned out from both Northwood and Griffith Park sites to accelerate this activity.

The tunnel clean-out consists of:

- Repairs of any outstanding ring damage or water leakage;
- Removal of tunnel conveyor, pipes (except fire main and drainage);
- Removal of unnecessary electrics (but small power, lighting and comms to remain);
- Cleaning the tunnel lining; and
- Final as-built alignment using 3D last scanning 'point cloud' technology.

5.6 Trackbed

The track along the entire alignment will consist of slab track, which is widely used on the Luas system in Dublin. Slab track consists of a concrete slab or sleepers as a base to which the rail line is attached.

The trackbed concrete is shown in Diagram 5.1 below. It is proposed that this is made up from two levels:

- A first stage bulk infill, which will contain the drainage and cross-ducts where necessary; and
- A 'top-up' second stage, which is poured around the sleepers after the installation and welding of the track. The second stage concrete will contain the stray current protection (continuous pieces of rebar, welded together and checked for continuity), the drainage channels and manhole access to drainage and cable pits.

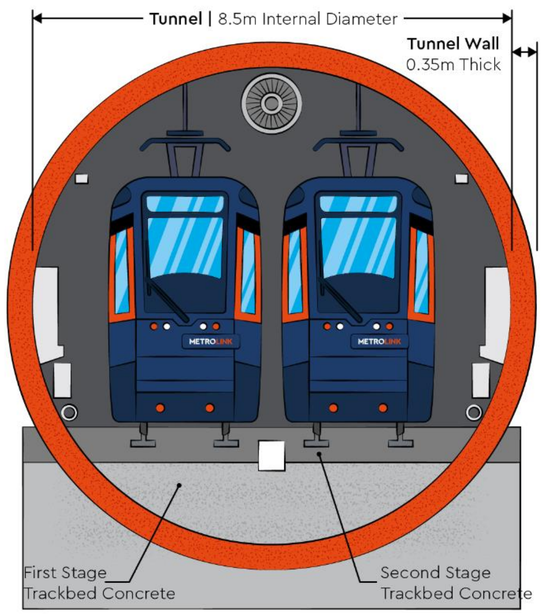


Diagram 5.1: Bored Tunnel Track Bed Concrete

The first stage follows the tunnel clean-out and the second stage follows the track installation. The top of rail is approximately 2.2m above tunnel invert. The concreting split has been selected as:

- First stage: 1.5m deep (6.75m3 per linear m); and
- Second stage: 0.4m deep (2.7m3 per linear m).

This allows the majority of the concrete to be placed prior to the track, making the track installation easier. Concrete is laid using a paving machine. Concrete is supplied from the launch site via truck which discharges into a storage hopper which then supplies the paver. Concrete will be site batched, ensuring a continuous supply 24hour/day, 7 days/week.

The activities required to install the first stage track bed concrete, to install the track, and to place the second stage concrete track bed that provides the final finished surface are detailed in Appendix 5.15 (Track Laying Methodology) of this EIAR.

6. Programme

6.1 General

The TBM drive will occupy over 30% of the entire programme critical path (from Contract Award to start of operation).

The ‘tunnelling works” (from order of TBM to start of tracklaying) form over 70% of the project critical path. The project critical path is:

- Order, design, manufacture, test, dismantle and ship to site, the TBM for the City drive;
- At the same time, take possession of the Northwood site and construct the portal, preparing this for the TBM arrival;
- Erect and commission the TBM;
- Construct the tunnel as far as the TBM burial position south of Charlemont;
- Dismantle the majority of the TBM and back-up equipment, and ‘bury’ the remainder;
- Tunnel clean out;
- First stage trackbed concrete;
- Install track and place second stage trackbed concrete;
- Install tunnel MEP systems;
- Testing and commissioning; and
- Trial running.

6.2 Working Hours and Shift Pattern

Tunnelling is a cyclic process and reaching a ‘safe stop’ point cannot easily be arranged for a shift end. It is therefore proposed to work 24 hours a day, 7 days a week for the tunnelling works using a 3 x 8 hr shift pattern, with a total of 4 crews. This comprises a day shift from 7am to 3pm, a back shift from 3pm to 11pm, a night shift from 11pm to 7am and one crew on shift break. The crews would rotate day, back and nights on a 7on, 2 off, 7 on, 2 off, 7 on 3 off system. The 3 days off usually is at the end of a set of day shifts, see Diagram 6.1 below. Contractor(s) will propose their own shift patterns to suit 24hr working.

	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu
Shift 1	D	D	D	D	D	D	D	O	O	O	N	N	N	N	N	N	N	O	O	B	B	B	B	B	B	B	O	O
Shift 2	O	O	O	N	N	N	N	N	N	N	O	O	B	B	B	B	B	B	B	O	O	D	D	D	D	D	D	D
Shift 3	N	N	N	O	O	B	B	B	B	B	B	B	O	O	D	D	D	D	D	D	D	O	O	O	N	N	N	N
Shift 4	B	B	B	B	B	O	O	D	D	D	D	D	D	D	O	O	O	N	N	N	N	N	N	N	O	O	B	B

D = days   N = nights   B = backs   O = off shift

Diagram 6.1: Indicative Working Shift Pattern for Continuous Tunnelling

Shift reporting will be done by the TBM Engineers using a web base tunnel management system that can also include quality records and sign off sheets, maintenance checks and safety inspections. Being web based means an internet connection in the TBM control room is required but this a commonplace with TBM manufactures wanting to remotely interrogate the machines Programme Logic Control (PLC) if a break down occurs. Web based also provides a live progress report during the shift that can be viewed by authorised personnel and the production of weekly reports such as progress or break downs at the touch of a button.

The tunnel management system can be tailored to include maintenance checks and can be set to flag up any items that are due or have been missed from the daily or weekly inspections. This allows the Electrical and Mechanical Engineers to plan preventative maintenance into the weeks work plus provides an invaluable record of inspections and lifespan of individual components.

6.3 Tunnelling Progress Rates

In view of Section 6.1, it follows that the speed of tunnelling is of huge importance to the overall project. There are two aspects to consider:

- Ensuring that the best possible advance rate for the whole alignment is achieved; and
- Accurately predicting what that advance rate will be.

The choice of TBM will have an effect on the advance rates achieved along with a number of other factors, including:

- The ground and groundwater conditions;
- The TBM crew have a major influence on progress rates with a good team working well and smartly together. High calibre individuals in key roles, such as works manager, pit bosses and front-line supervisors can make all the difference for a smooth running TBM;
- Whilst it is important to have the TBM running smoothly, the back-up logistics are equally important, ensuring that rings, grout and other material are delivered on time while spoil is removed. Matching the size and type of the construction railway / spoil handling equipment to the anticipated progress rates is an important part of the process and must be undertaken with as much detailed planning as that of the TBM itself; and
- Planned maintenance is an essential part of achieving good progress rates and must not be considered for the TBM alone but for the system as a whole, from the surface plant and grout batchers to segment and spoil handling and locomotives and rolling stock.

6.4 Tunnel Logistics

A TBM is very much a 'mobile factory', using repeat processes to rapidly and consistently produce completed tunnel in one ring units. It is important that the supply logistics closely match the TBM requirements.

The tunnelling will require the following logistics:

- Excavated material out via conveyor or slurry pipes. For the longer City drive booster station will be required for the conveyor and the slurry will require a number of stage pumps;
- Pre-cast concrete tunnel ring segments will be handled on surface by forklifts and cranes before being taken into the tunnel on a rubber tyre bi-directional multi-purpose vehicle (see Diagram 6.2). Alternatively, a narrow-gauge construction railway can be used; and
- Grout will be mixed on surface in a purpose-designed batching plant and either pumped to the TBM or transported in on the multi-purpose vehicle.

Diagram 6.2: Typical Service Vehicle

6.5 Tunnel Completion

Following completion of the tunnel drive and dismantling of the TBM, the following operations must take place:

- Tunnel clean out;
- Drainage and first stage invert concrete;
- Track laying and second stage concrete;
- Installation of fire main and pump mains;
- Installation of the overhead conductor rail (OCR);

- Installation of power and lighting;
- Installation of signalling, communication and other systems;
- Integrated testing and commissioning; and
- Trial running.

6.5.1 Tunnel Clean Out

On completion of the Airport Tunnel, the tunnel will be cleaned out working from DANP to DASP.

On completion of the City Tunnel, it is proposed that the tunnel will be cleaned out from both Northwood and Griffith Park sites to accelerate this activity.

6.5.2 First Stage Concrete

The first stage tracked concrete follows the tunnel cleanout. A progress rate of 200m3 of concrete per 8hour shift (600m3 per day) has been assumed.

6.5.3 Tunnel Fit-out

Tracklaying is assumed to progress at 75m of tunnel per day (i.e. 150m of track). Work is assumed to be 24hrs/day, 7days/week.

A progress rate of 75m of tunnel per day, 7 days per week is assumed. This will require approximately 200m3 of concrete per day (24hours) for the Second Stage concrete.

6.5.4 Trial Running and Operator Training

Following stand alone and integrated testing and commissioning, trial running will take place. This will initially be for the section from Estuary to the depot at Dardistown. This work will be carried out to ensure the control and failsafe functions are all working correctly and operational and maintenance personnel are trained in normal and degraded service and in a variety of emergency scenarios.

7. Environmental

7.1 Working Hours

Standard working hours for the tunnelling works will be 24 hours per day and 7 days per week. However, HGV deliveries to site and the removal of excavated material is likely to be limited to:

- 7am to 7pm Mondays to Fridays;
- 7am to 1pm Saturdays; and
- No deliveries Sundays.

It is anticipated that a number of special loads will be required to be delivered and collected outside these hours (e.g. piling rigs and the large TBM parts), because An Garda Siochana or Local Authorities will require these to be delivered 'over-night.'

Anticipated working hours are shown in Table 7.1.

Table 7.1:Schedule of Working Hours

Activity	5.5 days per week	7 days per week	11 hrs per day	24 hrs per day	Extended days	Overnight
Station and shaft works	✓		✓			
All works associate with tunnelling, including the passage of the TBM through the station		✓		✓		
Other tunnel-related activities (e.g. clean-out, track bed, tracklaying and M&E fit-out.)		✓		✓		
Compensation grouting (if required)		✓		✓		
Roadworks (as directed by the relevant authorities)	✓					✓
'Special' deliveries (as directed by the relevant authorities)	✓				✓	✓

7.2 Materials

The main material requirements for the tunnelling are shown in Table 7-2.

Table 7.2: Summary of Main Materials Required to Site

Material	Transport Method
Excavated material	Road (tipper)
Pre-cast concrete tunnel rings	Road (Flat trailer)
Cement and PFA	Road (Tanker)
TBMs (in sections)	By ship and then road (Low loaders & flat trailers)
Pipes, brackets, etc…	Road (Flat trailer)
Foaming agents and polymers	Road (curtain sider)
Bentonite	Road (Tanker)

7.2.1 Excavated Material

The type of excavated material will depend on the operating mode of the TBM.

7.2.1.1 Slurry Mode

A slurry of excavated material and water is formed in the head of the TBM, and as it is cut, it is mixed in a bentonite slurry, in order to reduce wear in the cutting head and slurry pumps. Bentonite powder will be added to the slurry to help form a cake over the cut ground to maintain face pressure in certain ground conditions such as lose or fractured ground and in sandy clays. Bentonite is blended from naturally occurring clay minerals and is supplied in a fine powder form. Polymers may also be added to the slurry to prevent the mix flowing to the ground under the pressure inside the head and to help prevent the mix sticking to metal surfaces. The slurry is subsequently pumped through a series of booster pumps along the tunnel, up to the surface and into a bentonite slurry treatment plant. Further information on the use of bentonite is contained in Appendix A5.13-B (TBM Consumables) of this EIAR.

The treatment plant separates the excavated material from the bentonite slurry. The treatment process separates the excavated material by size and a number of stockpiles are produced before removal from the site. The screening technology includes hydro-vacuum cyclones, vertical separators and centrifuges to ensure that fine particles are removed. The separated bentonite slurry is held in storage tanks and then pumped back down to the TBM for re-use.

On completion of all tunnelling works the bentonite slurry will be disposed of to a designated waste disposal site. During tunnelling, spent bentonite that is no longer suitable for reuse will also need to be disposed of on occasions. Transport of the bentonite slurry will be by road tanker. Under Irish regulations it is classified as a non–hazardous waste. It will not be possible to reuse, recycle or recover this waste further and disposal to a licenced landfill may be required.

Detailed description on resource and waste management and potentially suitable destinations for spoil and bentonite slurry transported by road are discussed in Chapter 24 (Resource & Waste Management) and in the Excavated Materials Management Strategy (Appendix A24.1) of this EIAR.

7.2.1.2 EPB Mode

Excavated material is mixed with spoil conditioning additives to make the cut ground more consistent and easier to handle, it will reduce friction in the cutterhead and reduce tool wear and a subsequent reduction in power used to turn the cutter head. In addition, the spoil conditioning additive helps by allowing the spoil to form a pressure plug in the screw conveyor which is fundamental to the operation of an EPB TBM and its ability to maintain face pressure.

The spoil conditioning additives generally consist of a detergent that is mixed with water in foam generators on the backup gantries to produce a thick shaving-like foam than can be injected into the chamber in front of the bulkhead. In addition to the foam, polymers can be added to reduce the clogging (stickiness) of the clay. The foam breaks down after a few hours or days. All materials are non-hazardous and biodegradable with no harmful residual chemicals. Further information on the use of spoil conditioning additives is contained in Appendix A5.13-B (TBM Consumables) of this EIAR.

Excavated material is expected to be transported out of the tunnel on a conveyor. As the TBM advances forward, the conveyor is extended.

The tunnel conveyor would transfer into a vertical conveyor which lifts the material to surface. Alternatively, the site may be suitable for a set of inclined conveyors.

The excavated material is then transferred across site to a storage stockpile. A radial or tripper conveyor will then be used to distribute the material around the stockpile to:

- Prevent overloading of the external and internal walls; and
- Separate differing materials or water content.

The stockpile would be:

- Installed on a concrete base which slopes to drains to encourage drainage;
- Provided with suitable lighting for 24-hour operation; and
- Serviced by a tracked excavator or wheeled loader. During traffic hours this would load the material into HGVs. Outside traffic hours, it would be used occasionally for re-distribution of material around the stockpile.

The anticipated quantities from the tunnel excavation are shown In Table 7-3.

Table 7.3:Anticipated Excavation Volume for the Running Tunnels

Tunnel	Mined Length (m)	Diameter (m)	Volume (m^3)	Number of HGVs
Airport Tunnel	2,310	9.5	163,733	20,467
City Tunnel	8,691	9.5	616,081	77,002

7.2.2 Other Materials

7.2.2.1 Tunnel rings

The proposed Project will require a large number of pre-cast concrete segments to be manufactured. Tunnel rings will be cast off site in a specialist plant as described in Section 4.6. These concrete segments will be stored at the Northwood Construction Compound and at the drive sites.

The current assumption is that each ring is 1.8m long. The anticipated volumes are given in Table 7.4.

Table 7.4: Anticipated Numbers of Tunnel Rings Required

Tunnel	Mined Length (m)	Ring length (m)	Tickness (mm)	Number of rings
Airport Tunnel	2,310	1.8	350	1,283
City Tunnel	8,691	1.8	350	4,828

Table 7.5: Anticipated HGV Numbers for Supply of Tunnel Rings

Tunnel	Mined Length (m)	Number of rings	Weight per ring	Number of trucks
Airport Tunnel	2,310	1,283	32.6	1,426
City Tunnel	8,691	4,828	32.6	5,364

7.2.2.2 Grout

The annulus around the pre-cast segmental linings and the cut ground, will be filled by a cementitious grout as the TBM moves forwards. The anticipated volumes are given in Table 7.6.

Table 7.6:Anticipated excavation volume for the running tunnels

Tunnel	Mined Length (m)	Grout thickness (mm)	Volume per lin m (m^3)	Number of trucks
Airport Tunnel	2,310	150	5.1	463
City Tunnel	8,691	150	5.1	1743

7.2.2.3 Invert Concrete

The first stage invert concrete requires a fill volume of approximately 7.4m3 per linear metre of running tunnel. This is then supplemented by a further 2.6m3 per linear metre of tunnel of second stage trackbed concrete, which is placed as the trackbed is installed. See also section 6.8.

A variety of sites will require these works, as shown in Table 7.7.

Table 7.7: Anticipated Invert and Trackbed Installation Volumes

Site	Type	Section complete	Length of tunnel (m)	Volume conc (m^3)	Number of trucks
Airport South	1st stage invert	Airport Tunnel	2,193	16,228	1,352
Northwood	1st stage invert	Griffith Park to Northwood	3,090	22,866	1,906
Griffith Park	1st stage invert	South of Charlemont to Northwood	5,369	39,731	3,311
Estuary	Trackbed	Estuary to Airport North	0	0	0
Dardistown Depot	Trackbed	Depot to Airport North & South of Charlemont	2,310 & 9,260	30,082	2,507

7.3 Traffic

7.3.1 Traffic Hours

It is assumed that HGV vehicle delivery times to the tunnelling sites will generally be restricted to:

- Monday to Friday: 07:00 to 19:00;
- Saturday: 07:00 to 13:00; and
- Sunday / Bank holidays: None

The exceptions to these would include:

- 'Special' deliveries where the Police or Transport Authority require 'out of hours' transport or where critical works overrun.

7.3.2 HGV Numbers

The numbers of HGVs required per day are larger than for any other activity on the project. The calculation behind these HGV numbers is included as Appendix A.

Haul routes are detailed in Section 2 and discussed further in the Scheme Traffic Management Plan (STMP) in Appendix A9.4 of this EIAR. Construction phase traffic impacts are assessed in Chapter 9 of this EIAR (Traffic & Transport).

7.3.3 Staff and Worker Travel

Approximate numbers of staff and workforce at key stages are shown in Table 7.8.

Table 7.8:Approximate Number of People Per Day

Key Stage	Numbers of people per day			
	Workforce		Staff	
	Days	Nights	Days	Nights
Tunnelling	52	48	24	8
Tunnel clean-out	40	36	18	7
Trackbed concrete Stage 1	50	46	16	5

All staff and workforce will be requested to make their way to site and home from site by public transport or by bicycle where possible. Only a limited number of parking spaces will be made available for staff and workforce, with additional spaces for vehicles required for the construction (e.g. fitter's van). Secure storage for bicycles will be provided on site.

The Contractor may decide to offer a minibus pick-up and drop off service from suitable stations.

7.4 Noise & Vibration

Chapter 13 (Airborne Noise & Vibration) and Chapter 14 (Ground-borne Noise & Vibration) of the EIAR outline the baseline noise and vibration levels and proposed mitigation measures.

8. Appendices

Appendix A: HGV Requirements based on typical advance rates

Appendix A: HGV requirements BASED ON TYPICAL ADVANCE RATES

Progress rate	80	100	120	m/week
Quantity of excavated material per week (solid)	5671	7088	8506	
Capacity of 1 HGV (m3 solid)	8	8	8	
No of HGVs per week	709	886	1063	
No of HGVs per day (assuming 5 days/week transport)	142	177	213	
Inner diameter (m)	8.5	8.5	8.5	
Cut diameter (m)	9.5	9.5	9.5	
Segment thickness (mm)	425	425	425	
Volume concrete per ring	15.46	15.46	15.46	
Weight concrete per ring	37.11	37.11	37.11	
Assume segments per ring	10	10	10	
Weight per segment	3.71	3.71	3.71	
Max segment lorry load (tonnes)	32	32	32	
Segments per HGV	8	8	8	
No of HGVs per week	56	69	83	
No of HGVs per day (assuming 5 days/week transport)	11	14	17	
Thickness of grout (mm)	75	75	75	
Vol of grout per ring	4.06	4.06	4.06	
Weight of powder per ring	4.47	4.47	4.47	
Weight of powder per week	199	199	174	
Powder per HGV	24	25	26	
HGV's per week	8	8	7	
No of HGVs per day (assuming 5 days/week transport)	2	2	1	
Miscelaneous HGVs per day	5	5	5	
Total HGVs per day	**160**	**198**	**236**	
Assume 8am to 6pm (= 10hrs)				
HGVs per hour	16	20	24	
Which is 1 HGV every	3.8	3.0	2.5	mins