RPA
Railway Procurement Agency

METRO NORTH ORAL HEARING

Design Input Statement for Predicting Ground Movement—Part 9

3 DESIGN STATEMENT

3.1 Description of Work

The proposed Parnell Square Stop will be connected to Mater to the North and O'connell Bridge to the South by bored tunnels at each end. The length of the stop box structure is approximately 122m. The rail level of Metro North at the Parnell Stop is constant at -12.83m AOD to provide a level platform.

The final formation for the Stop structure is assumed to be at -16.43m AOD based on the preliminary structural layout drawings. The ground level rises from approximately 8m AOD at the South to 13m AOD at the North. Therefore the depth of excavation for the Parnell Square Stop will vary from approximately 24m to approximately 29m below ground level.

3.2 Ground Conditions

At present there is limited geological data within the zone of the Parnell Square Stop, but the boreholes BH12 which is approximately 20m to the West of the proposed Parnell Square Stop indicates a depth of 3.4m of made ground which is underlain by Boulder Clay of approximately 6.8m thick. The Boulder Clay is in turn underlain by a layer of Glacial Gravels down to Limestone at approximate level of -20m AOD.

The preliminary ground water level to be adopted for the temporary retaining wall design will be as follow:

Stop	Construction Stage	Accidental Stage
Parnell Square (North)	+4.5m AOD	+10m AOD
Parnell Square (South)	+4.5m AOD	ground level

Notes:

1.The preliminary design groundwater levels are based on limited ground investigation data. Design groundwater levels will be reviewed based on data obtained from the ongoing preliminary ground investigation and proposed detailed ground investigations

3.3 Existing Buildings and Structures

The Stop is located under Parnell Square East which runs from the North of O'Connell's Street. On the East side of the road there is a row of 4 storey houses with basements that extend under the footway and possibly under the road. On the West there is a drop in level from the Parnell Square East down to the Rotunda Hospital. To the North is the Garden of Remembrance and Abbey Church and at the South of the Stop there is the Gate Theatre.

3.4 Existing Utilities

The Stop is located underneath Parnell Square East and the current utilities information indicates that the Stop will clash with the following:

- Watermains

- Gas mains
- Large diameter drainage pipe
- Power cables
- Tele-communication cables

These utilities will need to be either temporarily or permanently diverted to facilitate the Stop box construction which will need to be investigated as the Reference Design develops.

3.5 Method and Sequence of Construction

Temporary Cofferdam

The depth of excavation and restraints on the existing structures at the Parnell Square Stop will necessitate the construction of a rigid braced cofferdam to retain the temporary cut. The length of the cofferdam is likely to be at least 122m in which to construct the box structure. The width of the cofferdam will be approximately 20m.

In view of the space limitation and nearby sensitive structures and utilities, the only viable option is to adopt diaphragm wall construction for the excavation in the clay and sandy gravel layers down to formation level. The diaphragm wall with multi-level struts and walings, is to be used as the temporary retaining wall as well as the permanent wall for the Stop box structure.

Sequence of Construction

The suggested sequence of construction of the diaphragm wall works for the Cut and Cover Stop is to commence at the higher ground level end at the North and work towards the South.

The diaphragm wall would be constructed first with the shear pins and tension piles installed through the base of the diaphragm prior to the main excavation. Excavation would be in stages with the installation of struts and walings at each excavation level. The bottom level of struts will be installed close to the formation level and would be removed after casting and curing of the concrete slab on the final formation. The levels of the struts will be determined by the levels of the base slab, concourse slab and roof slab of the permanent box structure. As the structure is cast, the struts and walers will be removed and the lateral loads would be transferred to the permanent structure. The design of the struts and walings will need to be carried out in conjunction with the design of the permanent stop structure.

The water level within the excavation will be maintained at 0.5m below the excavation level at each stage.

4 DESIGN CRITERIA

4.1 General

The design of the temporary works will follow current best international design and construction practice and will comply with relevant British Standards.

4.2 Design Standards and Codes of Practice

The design standards and codes of practice to be adopted on this project are as listed in Table 4.2.1 below:

Table 4.2.1: List of Structural Design Standards

Codes and Documents	General Application
Geotechnical	
BS5930:1999 – Site Investigation	Ground investigation, in situ testing and lab testing
BS8002:1994 – Earth Retaining Structures	Design of below ground structures
BS8004:1986 – Foundations	Design of Foundations
BS8081: 1989 Ground Anchorages	Temporary retaining structures
BS EN 1538:2000 Execution of special geotechnical works - Diaphragm Walls	Diaphragm wall design
BS EN 12063:1999 Execution of special geotechnical works – Sheet pile walls	Temporary Sheet pile wall design
BS EN 1536:2000 Execution of special geotechnical works – Bored Piles	Bored Pile design
BS EN 1537:2000 Execution of special geotechnical works – Ground anchors	Ground Anchor Design
BS EN 12715:2000 Execution of special geotechnical works – Grouting	Grouting Design
CIRIA R101 – A Guide to the Use of Rock Reinforcement in Underground Excavation	Rock Bolt Design
CIRIA R113 – Control of Ground Water for temporary Works	
CIRIA C504 – Engineering in Glacial tills	Design of below ground structures
CIRIA C514 – Grouting for ground engineering	Building protection design
CIRIA C515 – Groundwater control	Design of temporary ground water control
CIRIA C517 – Temporary propping of deep excavations	Temporary works design
CIRIA C580 – Embedded Retaining walls – Guidance for economic design	Design of Stop / entrance walls
ENFARC European Specification for Sprayed Concrete	Temporary or permanent support of excavated faces in soil and rock

Codes and Documents	General Application
Structures	
BS8110 Structural use of concrete Part 1: 1997 Code of practice for design and construction Part 2: 1985 Code of practice for special circumstances	Structural design and detailing for reinforced concrete elements
BS5950 Structural use of steelwork in building: Part 1: 2000 Code of practice for design in simple and continuous construction: hot rolled sections Part 2: 2001 Specification for materials, fabrication and erection: hot rolled sections	Structural design and detailing for structural steel elements
BS8102 – Protection of structures against water from the ground	Classification of basement spaces

4.3 Geotechnical Design Parameters

The following recommended geotechnical design parameters represent moderately conservative values based on data collected along the entire alignment of the proposed Metro North. The interpretation and recommendation of these geotechnical design parameters for Reference Design purposes is based on available ground investigation data, relevant published data and both local and general experience, but excludes the IGSL Preliminary GI in-situ and laboratory test data, which has not yet been received in final form. In adopting the recommended values, local variations will be considered by reference to specific relevant ground investigation results that become available during design stage.

Table 4.3.1: Recommended Soil Material Properties

STRATUM	CLASSIFICATION					
	Bulk Unit Weight, γb	Moisture Content *w*	Atterberg Limits (%)			
	(kN/m³)	(%)	LL	PL	PI	LI
Made Ground	18.0					
Alluvium (Cohesive)	17.0					
Alluvium (Granular)	18.0					
Glacial Gravels	20.0					
Brown Boulder Clay	22.0					
Black Boulder Clay	22.0	11 ± 3	25 ± 4	14 ± 2	11 ± 2	-0.2 ± 0.003

Table 4.3.2: ***Recommended Soil Strength Parameters***

STRATUM	STRENGTH		
	Effective Cohesion c'	Effective Angle of Internal Friction Φ'	Undrained Shear Strength c_u
	(kPa)	(°)	(kPa)
Made Ground	0	32 (old) 30 (new)	-
Alluvium (Cohesive)	0	30	20
Alluvium (Granular)	0	32	-
Glacial Gravels	0	38	-
Brown Boulder Clay	0	35	100
Black Boulder Clay	0	37	250

Table 4.3.3: ***Recommended Soil Stiffness Parameters***

STRATUM	PARAMETER						
	Drained Modulus E'	Undrained Modulus E_u	In situ OCR	Poisson's ratio v	k_0	ka	kp
	(MPa)	(MPa)					
Made Ground	15 (old) 10 (new)	-	-	0.25	0.5	0.31 0.33	4.5 4.25
Alluvium (Cohesive)	3	10	-	0.25 (0.5)	0.5	0.33	4.25
Alluvium (Granular)	15	-	-	0.25	0.5	0.31	4.5
Glacial Gravels	50	-	-	0.25	0.4	0.25	7.3
Brown Boulder Clay	35	50	8 to 30	0.3 (0.5)	1.5	0.28	6.0
Black Boulder Clay	60	90	8 to 30	0.3 (0.5)	1.5	0.26	6.7

Table 4.3.4: Recommended Soil Permeability

STRATUM	PERMEABLITY
	k
	m/s
Made Ground	-
Alluvium (Cohesive)	-
Alluvium (Granular)	$5 \times E^{-4}$
Glacial Gravels	$2 \times E^{-5}$
Brown Boulder Clay	$1 \times E^{-11}$ to $1 \times E^{-8}$
Black Boulder Clay	$1 \times E^{-11}$ to $1 \times E^{-8}$

4.4 Material Properties

4.4.1 Concrete Properties

The concrete properties to be used in the design are as follows:

Table 4.4.1: Concrete Properties

Concrete Cube Strength (N/mm^2)	35	40
E(short term) (kN/mm2)	27	28
E (long term) (kN/mm2)	13.5	14
Poisson's Ratio	0.2	0.2
Coefficient of thermal expansion, α (°C-1)	8×10^{-6}	8×10^{-6}

Notes:

1. All values in accordance with BS8110: Part 2:1985

4.4.2 Reinforcement Properties

Steel reinforcement used in the design shall have the following properties:

Table 4.4.2: Reinforcement Properties

Property	Value
Young's Modulus, E	200 kN/mm²
Poisson Ratio	0.3
Coefficient of thermal expansion, α	12 x 10-6 per °C

4.4.3 Structural Steel Properties

Structural steel used in the design shall have the following properties:

Table 4.4.3: Steel Properties

Property	Value
Young's Modulus, E	205 kN/mm²
Poisson Ratio	0.3
Coefficient of thermal expansion, α	12 x 10-6 per °C

4.5 Loading Data

4.5.1 General

The loads used in the design shall be in accordance with accepted international practice and relevant codes of practice.

4.5.2 Dead Loads

These are calculated in accordance with BS6399 and BS648 and the known unit weights of materials. The maximum and minimum self weights of concrete shall be considered in the design.

Table 4.5.1 Unit Weights of Concrete

Description	Max. Self Weight (kN/m^3)	Min. Self Weight (kN/m^3)
Reinforced concrete structural elements, placed insitu	25	23
Mass concrete, placed insitu	23.5	22
Lightweight mass concrete, placed insitu	22	14
Soil	22	18

4.5.3 Surcharge on Temporary Retaining Walls and Slopes

A 20kPa surcharge, acting on the active side of the excavation, will be allowed to cater for construction loading and temporary stockpile loading of excavated material on the temporary retaining walls and slopes.

A 40kPa surcharge will be applied at ground level along the eastern side of the excavation will be allowed to cater for the loading from the existing row of 4 storey houses.

4.5.4 Ground Loading

The prediction of horizontal earth pressures due to cofferdam excavations and the effect of the soil-structure interactions will be derived from numerical analysis using the Geotechnical Design Parameters given in Section 4.3 of this report.

4.5.5 Groundwater Design Levels

The groundwater design level to be adopted in the design of the temporary retaining walls and cut slopes shall be in accordance with Section 3.2 of this report. Design groundwater levels will be reviewed based on data obtained from the ongoing preliminary ground investigation and proposed detailed ground investigations. However it is recommended to adopt a*worse case groundwater level in the design to cater for seasonal variations in groundwater recharge.

* WORSE CASE MAYBE LOWER

4.5.6 Groundwater Drawdown

In order to minimise and control settlement due to deep excavations, the design of the temporary retaining walls and cut slopes will limit groundwater lowering by no more than 1.0m below the design groundwater level at the outside of the excavation.

4.6 Computer Software

The following computer software will be used in the design of the temporary works:

Software Name	Version	Purpose
FREW	8.11	Retaining Wall Design
PLAXIS	7	Numerical analysis of soil / structure interaction
SLOPE/W	4.24	Slope Stability Analysis
SEEP/W	4.2	Groundwater Modelling
PCSTABL5M	PC/5M	Slope stability analysis
FLAC	3.3	Numerical analysis of soil / structure interaction
DIPS	5	Rock Joint Analysis
UNWEDGE	3.0	Analysis of underground wedges
GRLWEAP	1977-3	Pile driving Analysis
Group	4.0	Pile group analysis
LPILE PLUS	WIN 2.0	Lateral loaded pile analysis
SWEDGE	4.0	Analysis of underground wedges

5 METHOD OF ANALYSIS / DESIGN APPROACH

5.1 Propped Retaining Wall in Soil

5.1.1 Introduction

The selection of the type of wall, and its thickness, is a function of the stiffness required, and any constraints and restrictions on construction techniques that apply in each area, for example spacing and members of layers of strutting.

Diaphragm Walls are to be used as the temporary and permanent lateral support.

5.1.2 Retaining Wall Stiffness

The stiffness of the retaining wall is governed by the section modulus, EI, where E is the Young's Modulus of steel section or concrete and I is the moment of inertia of the gross section.

5.1.3 Retaining Wall Toe Levels

The toe level of diaphragm walls will be designed to satisfy the following requirements:

- Toe Stability - the procedure outlined in CIRIA Report C580 will be followed in the analysis for the design of the retaining wall against the toe kicking out, throughout the various excavation stages. The minimum Factor of Safety (FOS) against failure from kick-out is 1.5.
- Groundwater Control - a check against hydraulic failure will be carried out using a Factor of Safety (FOS) against failure from piping or base heaving of 1.5.
- Control of groundwater drawdown outside the excavation

Toe stability will be assessed by considering moment equilibrium about the lowest prop level. Active and passive earth pressures will be calculated based on CIRIA C580 figure A 6.5 assuming the following wall friction angles:

On active side: 0

On passive side: ½ ϕ' (where ϕ' is the unfactored angle of internal resistance)

Geotechnical parameters such as soil shear strength and E values will be derived from Tables 4.3.1 to 4.3.4. For the purposes of toe stability calculations, a factor of safety of 2 will be applied to the passive earth pressure coefficient and hydrostatic water pressures will be assumed on both sides of the wall.

Where necessary, shear pins may be provided at the wall toe to provide sufficient toe stability. The shear pin will be modelled as a strut installed prior to excavation start. The horizontal force on the shear pin will be resisted by the reinforcement bars in shear which in turn transfer the load to the rock.

5.1.4 Strut Stiffness and Spacing

An initial assumption for the strut stiffness and spacing will be used in the retaining wall analysis. During detailed design, the stiffness will be adjusted, based on the strut force calculated in the analysis; and the spacing and pre-loading of the struts will need to be refined to minimise the lateral deflection of the retaining walls and to optimise the bending moment envelope.

5.1.5 Analysis of Retaining Walls

The analyses of retaining walls can be carried out using a soil / structure interaction program such as FREW or PLAXIS in order to determine the behaviour of the wall throughout the construction stages.

In general, the finite element program PLAXIS will be used for the analysis of the cofferdam excavation and to assess ground movements. The analysis will include consideration of all stages of the excavation and backfilling / installation and prop removal to obtain an envelope of the critical design effects. The movement of the adjacent existing structures may also be predicted by using PLAXIS. In case there is no sensitive structure adjoining to the cofferdam excavation, FREW may be used for the analysis to obtain results for design.

The following assumptions will be included in the analysis:

- A 500mm unplanned over-dig at every excavation level.
- A 250mm over-dig below the final formation level of the underside of the Stop box base slab is considered in all of the analyses.
- The water pressure around the wall will be assumed to be under steady-state seepage condition as a consequence of seepage flow beneath the wall toe.
- The propping design will include one degree of redundancy in that a one strut failure at any one level will be assumed. If a strut fails the adjacent struts either side of the failed strut will take the additional loads and will be sized accordingly. Also the walings will be sized to span between every first and third struts to allow for the one strut failure to prevent the risk of a lower factor of safety against excessive ground movement.

The active and passive earth pressure coefficients will be based on unfactored friction angle of the soil layers adjacent to the wall. Vertical surcharge due to construction traffic will also be included in design as required.

5.1.6 Serviceability Limit State (SLS)

The evaluation of the deflection of the walls and the corresponding ground movements are based on the SLS load combinations.

5.1.7 Ultimate Limit State (ULS)

The evaluation of the structural capacity of the retaining wall will be based on the results obtained from the earth pressure analysis using the unfactored soil parameters, (i.e. SLS analysis). The resulting bending moments, shear forces and prop forces will be factored by 1.4, based on BS8110, to give the maximum bending moments and maximum shear forces and axial loads that will be used in the design of the structural elements.

5.2 Ground Movements

5.2.1 Prediction of Green Field Ground Movements due to Cut and Cover Stop Box Construction

The installation of temporary retaining walls, dewatering and excavation will induce both horizontal and vertical ground movements, which may cause damage to the adjacent buildings, structures or utilities. Therefore an essential aspect of temporary work design for deep excavations is to predict the associated ground movements and assess the response of the adjacent properties.

The approach that will be taken to predict the response of buildings, structures and utilities to deep excavations firstly involves the assessment of greenfield site settlements and followed by an assessment of how the inherent stiffness of the building, structure or utility is likely to modify this ground settlement.

5.2.2 Major Causes of Ground Movements

For cut and cover excavations, the potential ground movements can be attributed to the following activities:

- Installation of diaphragm wall panels;
- Lateral deformation of the retaining walls during excavation;
- Groundwater drawdown outside the diaphragm wall associated with dewatering within the excavation.

5.2.3 Method of Prediction of Greenfield Ground Movement for Cut and Cover Tunnel Excavation

Installation of Diaphragm Wall

The settlement associated with installation of diaphragm wall can have a significant effect to the adjacent buildings and will need to be addressed according to the ground conditions. In sensitive zone, the length of panel will be reduced to limit the arching effect and measures such as raising the bentonite level in the excavation will be implemented to ensure ground stability.

Lateral Movements of the Retaining Walls during Excavation

During excavation, pressure from the surrounding soil will be transferred to the retaining structure resulting in movements of the ground and the wall. The magnitude of these movements will depend on the depth of excavation, the stiffness of the wall and the strutting system, the stiffness and strength characteristics of the soil both outside and below the excavation level, preloading and the construction sequence. In order to limit the deflection of the supporting wall, and thus reduce the ground settlement, preloading of struts may be adopted in the design.

Groundwater Drawdown Associated with Dewatering within the Excavation.

Groundwater drawdown outside the perimeter of the excavation may occur as a result of dewatering within the excavation.

The groundwater drawdown shall, be limited to maximum of 1.0 m below the design groundwater level in order to minimise ground movements. The prediction of groundwater drawdown induced settlement, ground water drawdown and ground water seepage will be analysed using finite element software SEEP/W.

5.2.4 Analytical Tools

PLAXIS

PLAXIS is a powerful two-dimensional continuum code for modelling soil, rock and structural interaction problems. The finite element formulation of the code makes PLAXIS ideally suited for modelling geomechanical problems that consist of multi-stages, such as sequential excavation, backfilling and loading. The formulation of the code can also accommodate large displacements and strains and non-linear material behaviour.

FREW

FREW (Flexible Retaining Walls) is a program that analyses flexible earth retaining structures such as sheet pile and diaphragm walls. The program enables the assessment of the deformation of the structure throughout a specified construction sequence. The programme calculates strut forces and earth pressures, displacements, bending moments and shear forces during construction.

SEEP/W

SEEP/W is a finite element software product for analysing groundwater seepage and excess pore-water pressure dissipation problems. The comprehensive formulation of SEEP/W makes it possible to consider analyses ranging from simple saturated steady-state problems to sophisticated saturated/unsaturated time-dependent problems.

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