Railway Procurement Agency

# METRO NORTH
# ORAL HEARING

## SD-2.6E Stage 2A Ground Movement Assessment Report RevA

# Mater Stop Existing Buildings and Structures Report

# Stage 2A: Ground Movement Assessment

# M000384/243231/ID-2-6E/A

RPA
PG2 Parkgate Business Centre
Parkgate Street
Dublin 9

# Mater Stop Existing Buildings and Structures Report

# Stage 2A: Ground Movement Assessment

# M000384/243231/ID-2-6E/A

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# Stage 2A: Ground Movement Assessment

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## Issue and Revision Record

| Rev | Date | Originator | Checker | Approver | Description |
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## Executive Summary

The RPA's 'Metro North Construction and Maintenance Requirements' (CMR's) require that an assessment be made of the effects of construction on all structures within the zone of influence of the works. The zone of influence for excavations from the surface is defined as the distance equating to twice the depth of the excavation originating from the sides of the excavation or the position of the predicted 1mm settlement contour line, whichever is the greater, (Ref. 1)

Technical Note 12 (Ref.3) : 'Strategy for Assessing and Managing Building, Infrastructure and Utility Response to Ground Movements Generated by Underground Excavation' was produced by Jacobs in May 2008 for RPA in order to outline how the requirements of the CMR could be met. Mott MacDonald have reviewed Technical Note 12 and adopted the criteria proposed for selecting those buildings and utilities to progress to Stage 2A assessment. The criteria proposed in Technical Note 12 for selecting infrastructure to progress to Stage 2A was deemed too stringent for the infrastructure in the vicinity of the proposed Mater Stop and site specific limits have been derived. Where Technical Note 12 contradicts the CMR the latter takes precedence.

This report provides the Stage 2A assessment of surface settlements and buildings response arising from construction of the proposed Mater Stop as part of the Dublin Metro North scheme. Values of predicted settlement have been re-assessed from the Stage 1 Preliminary Ground Movement Assessment Report and are presented as contours on background mapping and are included in Appendix A of this report. They are broadly similar to the values assessed at Stage 1.

The maximum predicted settlement immediately adjacent to the proposed Mater Stop is 29mm although as this occurs immediately adjacent to the box actual values are likely to be less due friction between the diaphragm wall and the surrounding soil. A maximum settlement of between 50mm and 60mm was previously predicted for Mater Stop in the Jacobs Stage 1 Preliminary Ground Movement Assessment Report. However, this higher value also took into account the effects of the tunnelling at either end of the box. This report concentrates solely on ground movement associated from construction of the Mater Stop Box and therefore does not take into account the effect of tunnelling. The number of buildings, structures, services and infrastructure within the construction zone of influence (1mm contour) included in the Stage 2A assessment are summarised below:

**Table S.1: Summary of Existing Buildings, Utilities & Infrastructure Included Stage 2A Assessment**

| Item | Number to Progress to Stage 2A |
|---|---|
| Buildings and Structures | 63 |
| Utilities and Services | 49 |
| Infrastructure Items | 7 |

The above include as a minimum all of the recommendations for Stage 2A assessment made in the Stage 1 report.

The potential building damage assessments were undertaken using the Mott MacDonald in-house software, *BREXIS* (Building Response to Excavation Induced Subsidence). The ground movement profiles generated by GRP were imported into *BREXIS* for subsequent analysis. Buildings with shallow foundations were modelled as deep beams, the foundations being assumed to follow the anticipated greenfield surface settlement trough. The maximum tensile strain induced in the building was determined and corresponding damage category assigned through reference to the work of Burland et al. (1977), Boscardin and Cording (1989) and Burland (1995), (Ref. 19, 20 & 21). The results of this analysis are discussed below.

The Mater Private Hospital is located at the south-east corner of the proposed Mater Stop box excavation. Analysis indicates a maximum settlement of 23mm for the corner of the 1 storey extension closest to the box reducing to 6mm for the main 5 storey section of the building. Maximum calculated tensile strains indicate that damage levels will not exceed the negligible category anywhere within the hospital. However, as this is a sensitive structure it is recommended that a Stage 3 assessment be undertaken to more closely look at differential movement between elements of the structure founded on different foundation systems.

The Mater Campus Hospital Development (MCHD) will be located immediately to the west of the box excavation and will also be partly supported by the roof of the completed box. The maximum calculated settlement at basement (founding) level of MCHD is 16mm and analysis indicates maximum tensile strains that would equate to damage levels within the negligible category. However, as this is a sensitive structure it is recommended that a Stage 2B assessment be undertaken to more closely look at building deformation. The building designer will also need to consider the potential for differential movement between elements of the structure founded adjacent to and upon the box.

A large number of domestic properties have been assessed. Analysis has indicated maximum tensile strains that would equate to damage levels within the negligible category for all of the properties. A large number of the properties in Leo Street have single and in one case, two storey extensions at the rear and damage is possible at the interface although current analysis indicates that damage levels are unlikely to exceed the *slight to moderate* category. However, this aspect should be re-assessed in the Stage 2B assessment when the results of trial excavations and condition surveys to be undertaken by RPA are available.

The only existing utilities currently giving rise for concern are the combined drainage runs in North Circular Road and Leo Street where recommendations have been made in the Drainage Impact Assessment Report for structural re-lining. All other drainage services are to be subject to CCTV survey and these, together with the findings from RPA slit trenches should be used to review all of the utilities in the Stage 2B assessment.

None of the existing highway infrastructure within the zone of construction influence is likely to suffer significant damage due to ground movements.

All infrastructure falling within the 10mm settlement contour line has been included in the Stage 2A assessment.

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# 1 Introduction

## 1.1 Scheme Overview

Metro North is the next phase of Dublin's integrated light rail network, which began with the opening of the Luas Red and Green lines. Metro North will provide park and ride spaces and good quality bus, rail and air interchanges along an 18 km corridor running from Belinstown in the North through Seatown, Swords, Fosterstown, Dublin Airport, Dardistown, Northwood, Ballymun, Dublin City University, Griffiths Avenue, Drumcondra, Mater Hospital, Parnell Square and O'Connell Bridge to St Stephen's Green in the city centre.

In June 2008, Mott MacDonald was commissioned by Railway Procurement Agency (RPA) to act as their Design Consultant for the Advanced Design Proposal for the Mater Stop. The scope included the production of a Stage 1 Preliminary Ground Movement Assessment Report and a Stage 2A Building Response Assessment Report. The outline methodology of the various settlement studies is presented in Table 2.1.

## 1.2 Objectives

The purpose of this Existing Buildings and Structures Report is to present the results of the Stage 2A Building Response Assessment. This is based on the results of analysis undertaken to predict ground surface movements and to identify the impact on existing buildings, utilities and infrastructure. Where damage levels are likely to exceed pre-set limits then those structures will be taken forward to the Stage 2B assessment.

It should be noted that a previous Stage 2A report was prepared by Jacobs (Ref 1) to cover the entire route and construction of the proposed Dublin Metro North whereas this report forms a stand-alone Stage 2A report, concentrating solely on the predicted ground movements relating to the excavation of the Mater Stop Box as designed by Mott MacDonald (MM). Predicted ground movements associated with tunnels that will enter and leave the box are excluded. This report is developed from the Mott MacDonald Stage 1 Settlement Assessment Report (Ref. 15) and will provide a schedule of all the buildings, utilities and infrastructure to be taken forward to the Stage 2B Assessment.

# 2 Overall Methodology

## 2.1 Overview

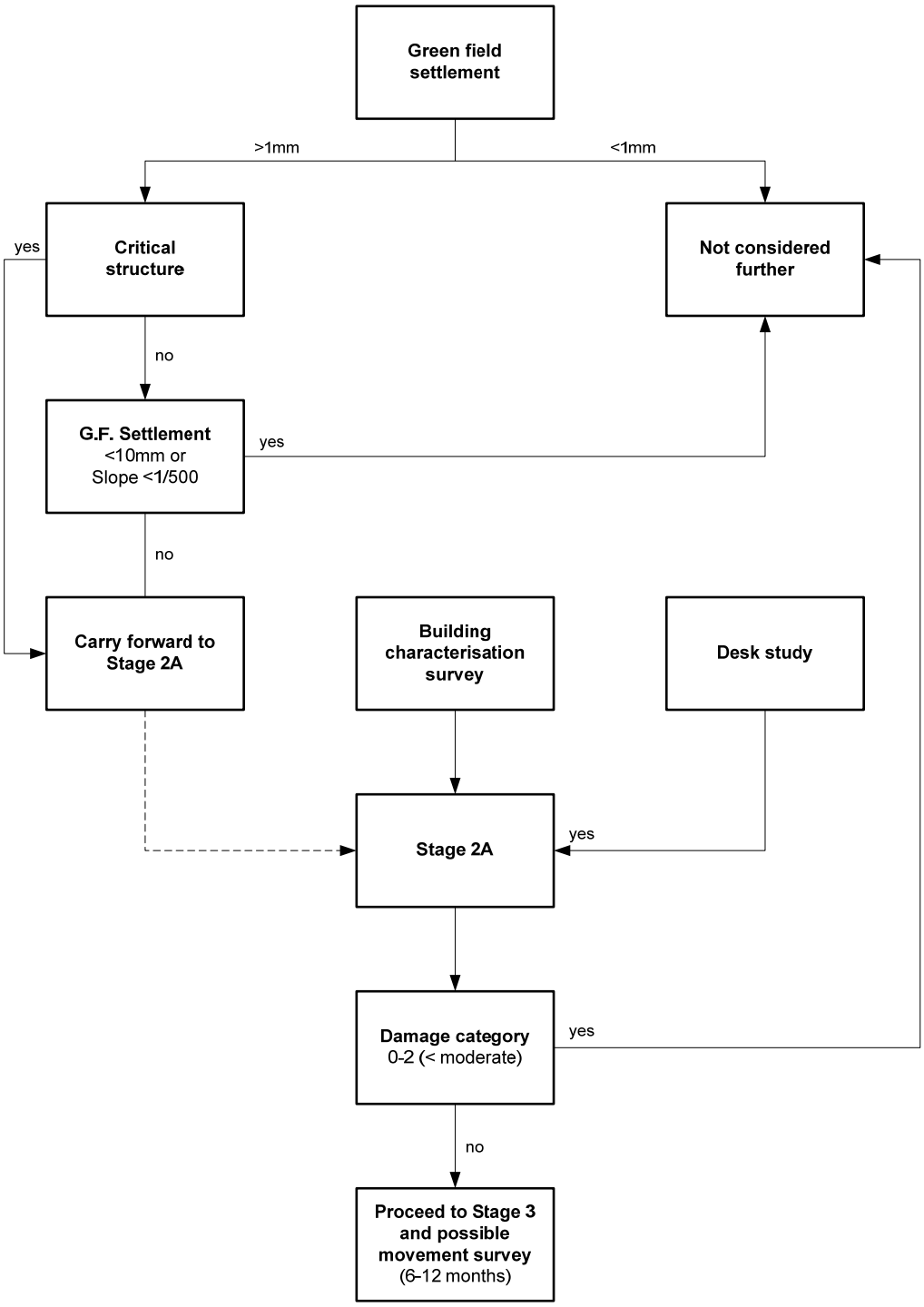
The method of predicting ground movement and assessing the behaviour of buildings, utilities and infrastructure is a progressive process. For Mater Stop a 4 Stage assessment process has been adopted based on the process developed by RPA for the Metro North as a whole. The various stages are summarised below in Table 2.1 and Figure 2.1.

**Table 2.1: Settlement Assessment Methodology and Stage Description (Mater Stop)**

| Stage | Description |
|---|---|
| 1 | Stage 1 Preliminary 'Greenfield' Settlement Analysis – prediction of ground movements generated by excavation for the Mater Stop and the identification of buildings, infrastructure and utilities at potential risk of damage. |
| **2A** | **Stage 2A Initial Response Assessment - assessment of the response of buildings, infrastructure, utilities (identified during Stage 1) to predicted ground movements, and where appropriate consideration of possible mitigation measures.** |
| 2B | Stage 2B Review of 2A Initial Response Assessment – the Design and Build Contractor to review the Stage 2A assessment in the light of actual construction techniques proposed. |
| 3 | Stage 3 Detailed Response Assessment – Detailed assessment of all buildings, utilities and infrastructure carried over from Stage 2B, and the design and implementation of protection measures as appropriate to be carried out by the Design and Build Contractor. |

The bold text indicates the current stage.

**Figure 2.1: Summary of Existing Building Assessment**



# 3 Ground Conditions

## 3.1 Ground Model

Ground conditions typically comprise a thin 2m crust of Made Ground over Glacial Soils over bedrock of the Lucian Calp formation at some 25m depth. The Glacial Soils contain both Glacial Till and Glacial Sands and Gravels.

The Glacial Tills are often colloquially termed “Boulder Clays” and are well known within the Dublin area where they are considerably stronger and stiffer than most normal sedimentary clays. Glacial Sand and Gravels horizons appear at varying depths across the site and in varying strata. Poor recovery and high variability across the site leads to a poor understanding of this material; however the majority of sand and gravel beds appear to occur within Subunits 1 and 2 of the Lower Brown Glacial Till Formation, (between 9mOD and -4.52mOD) as well as lenses within the Upper Black Glacial Till Formation, (between 15mOD and 8mOD). Sand and gravel lenses do not appear to occur outside of these strata and are interbedded within these strata with Glacial Till.

Bedrock comprises strong limestone with subordinate shale bands. Bedrock is determined as all material occurring below geological rockhead which is taken as the base of the Quaternary deposits.

Groundwater levels appear to be near surface within the upper Glacial Soils but at a lower elevation within the deeper Glacial Soils and bedrock with the latter apparently providing under-drainage and reducing the groundwater profile with depth to sub hydrostatic.

Further information regarding the ground and groundwater conditions together with full definitions of terms can be found in the Mater Stop Geotechnical Basis of Design Report, (April 2009), SD-2.6Aii. (Ref. 12).

# 4 Outline Construction Methodology

## 4.1 Construction Methodology for Mater Stop

The proposed Mater Stop will comprise a cut and cover box. There will be three main surface penetrations, one for the entrance off North Circular Road, and two for ventilation shafts. The structure will be designed so that at a later date the TBM can transit through the box.

The Stop box will be constructed from diaphragm walls toed into the underlying bedrock, and tension piles will be required beneath the base slab to prevent uplift. In the central area of the box, the design comprises of a concourse and platform level. In the back-of-house areas, additional floor levels are included to provide sufficient space for the M&E requirements. The majority of the internal structure will be constructed from reinforced concrete, with both the roof and concourse slabs being from a beam/slab arrangement. The box will be constructed using a top-down methodology.

# 5 Extent of Stage 2A Assessment

## 5.1 Stage 1 Preliminary Ground Movement Assessment

The Stage 1 Preliminary Ground Movement Assessment Report (Ref 15) identified the buildings, structures, services and infrastructure to be carried forward into the Stage 2A assessment process. The selection process was based on the predicted surface ground movements and in accordance with RPA's Construction Maintenance Requirements, CIRIA Project Report 30 and RPA's Technical Report 12.

All buildings etc within the construction zone of influence (defined as the 1mm settlement contour) were considered. All prominent (e.g., listed/protected) or sensitive (e.g., hospitals) structures were automatically included together with all others with a predicted greenfield settlement >10mm or ground slope in excess of 1:500. All existing structures with a current damage category of moderate or worse were also included.

For utilities the following limits, based on criteria within Technical Note 12 and work by Attewell et al (Ref. 9), were adopted as a basis for selecting those to be carried forward to Stage 2A :

- Brittle pipelines exceeding 10mm settlement.
- Ductile pipelines exceeding 50mm settlement.

Where accurate categorisation of utilities could not be made in accordance with the above assessment then they were assumed to be brittle pending further assessment at Stage 2A.

All infrastructure falling within the 10mm settlement contour were carried forward to Stage 2A.

Further details on individual elements recommended for Stage 2A assessment can be found in Ref 15.

## 5.2 Stage 2A Review of Preliminary Ground Movement Assessment

Following further ground investigation and a more detailed analysis of the deflections of the diaphragm walls a re-assessment of the Stage 1 conclusions was undertaken. Whilst this has lead to some small refinements of the Mater Box settlement model and some marginal differences in the Greenfield movements predicted the results of the Stage 1 assessment remain reasonable. On this base all buildings and infrastructure recommended for Stage 2A assessment in the Stage 1 report have been considered.

The revised predicted ground movements have been plotted as contours on the Metro North topographical survey background mapping. The topographical survey background mapping used in the development of the Stage 1 contour drawings was taken from the following model file; Drawing No. B MN 0791.

The predicted ground surface and sub-surface settlement drawings associated with this Stage 2A Report are listed in Table 5.1 are included in Appendix A.

**Table 5.1: Settlement Assessment Contour Drawings**

| Drawing Reference | Title |
|---|---|
| D MN 7091 GI 6008 D01 | Mater Stop – Predicted Settlement Contours Surface Level |
| D MN 7091 GI 6009 D01 | Mater Stop – Predicted Settlement Contours Mater Hospital Basement Level |

The settlement contour drawings depict predicted ground movement contours of 1mm, 5mm, 10mm, and 20mm with a maximum 28.6mm settlement predicted adjacent to the southern wall of the excavation.

## 5.3 Buildings and Structures included within the Stage 2A Assessment

All buildings and infrastructure recommended for Stage 2A assessments as detailed in the Stage 1 Preliminary Ground Movement Report, (November 2008), ID-1.6E/B have been included but using the Stage 2A settlement contours (Appendix A). A schedule of structures assessed is included in Appendix B. Table 5.2 summarises the numbers of buildings in the various ground settlement ranges within the zone of influence.

**Table 5.2: Summary of Existing Buildings within Influence Zone**

| Settlement Range | Number of Buildings |
|---|---|
| 1mm-10mm | 112 |
| >10mm | 63 |
| >30mm | 0 |

Of the 112 buildings within the zone of influence, 63 buildings have been included in Stage 2A Assessment. These are buildings with a predicted settlement greater than 10mm or a ground slope greater than 1/500 or are already in a damaged condition or arte sensitive to movement

Further details regarding the main groups of structures to be considered in the Stage 2A assessment are presented below.

### 5.3.1 Mater Children's Hospital

The proposed Mater Hospital extension will be constructed prior to the Mater Stop Box and as such, it will be treated as an existing building. The proposed Hospital extension will be 5-storeys in the main rising to 8-storeys in part all above a double level basement. The basement will extend to a depth of 10m below ground level. Mater Hospital extension will be founded on a 1m thick raft covering the entire footprint of the basement. Internal columns rising from the raft will support the floors above but it should be noted that part of the overlying structure will also be supported directly by the Mater Stop roof slab. (Ref. 11).

As described in Section 1 of this report an additional settlement analysis has been undertaken to predict greenfield settlement at the basement level of the proposed hospital extension. The results are presented as settlement contours on Drawing No. D MN 7091 GI 6009 D01, (Appendix A) which also shows the proposed basement layout and column locations.

### 5.3.2 Mater Private Hospital

A Characterisation Survey of Mater Private Hospital was conducted on behalf of RPA by building surveyor Jason McCann on 26th September 2007. Full details of this survey are presented in Appendix A of the Stage 1 Report.

Based on the survey the hospital was thought to have been constructed in around the 1980's. The building is constructed from concrete with a steel frame. The foundation type and depth is unknown, however the survey states that the building is likely to be supported on concrete piles. The building is approximately 15m high with 4 storeys as well as a basement. The structural form of the basement is unknown, however it is likely to be constructed from concrete.

Based on as-built drawings from the Day Therapy Extension the hospital height appears to be approximately 20m high with the number of storeys varying from 4 to 6.

### 5.3.3 Leo Street Properties

There are a total of 24 properties within Leo Street included within the Stage 2A assessment, as Nos. 25-26 are scheduled for demolition in advance of the excavation works.

A Characterisation Survey of the Leo Street Properties was conducted on behalf of RPA by building surveyor Brian Malone on 24 September 2007. Full details of this survey are presented in Appendix A.

Based on the survey the properties are thought to have been constructed in the mid-1800's. Deeds from 1846 have been confirmed for 21 Leo Street meaning that construction of the terrace must be pre-1846. All properties within Leo Street are terraced and constructed from masonry (red brick). Foundation type and depth is unknown, however the survey states that it is believed the terrace is founded on stone foundations at a depth of 0.6m with masonry rising walls. All properties are two storeys with height to ridge varying along the terrace from 6.5m to 8m, with an average of 7.5m. None of the properties have basements, however most have a single storey extension at the rear, with 5 Leo Street extended over two storeys at the rear.

At the time of preparing this report RPA are currently arranging for trial holes to be dug at selected properties to obtain further details of foundation types and depths. The results of this investigation will be available for inclusion in the Stage 2B assessment.

### 5.3.4 North Circular Road Properties

There are a total of 17 properties on North Circular Road included within the Stage 2A assessment, as 398 and 400 are scheduled for demolition in advance of the excavation works.

A Characterisation of the North Circular Road Properties was conducted on behalf of RPA by building surveyors Jason McCann, Brian Malone and Paul Finlay between the dates of 19th September and 5th October. Full details of this survey are presented in Appendix A.

Based on the survey the properties are thought to have been constructed between the early 1800's and early 1900's. All properties are terraced and constructed from masonry (red brick). Foundation type and depth is unknown, however the survey states that it is possible the terrace is founded at 0.5m depth on stone foundations with masonry. All properties are two storeys with height to ridge varying along the terrace from 6m to 8m. None of the properties have basements, however some have been extended.

### 5.3.5 Other Properties

There are a total of 17 properties on St Joseph Street, Josephine Avenue or Leo Avenue included within the Stage 2A assessment.

A Characterisation Survey was not conducted for properties on St Joseph Street, Josephine Avenue or Leo Avenue as part of the Jacobs Stage 1 Report. A visual survey of these properties was conducted by a Mott MacDonald Engineer on the 5th August 2008. The results of this survey are included in Appendix B of the Stage 1 report (Ref 15).

The precise construction date of these properties has not been determined as part of this report, however the buildings are possibly of a similar age to those in North Circular Road and Leo Street. The properties are terraced and constructed from masonry (predominately red brick). The properties are two storeys high and appear to be a similar height to those in Leo Street.

The properties do not appear to have basements. Foundations are likely to be similar to those expected in Leo Street and North Circular Road. As no access was gained to the rear of the properties, it is unknown as to where any of the properties have been extended.

## 5.4 Utilities included within the Stage 2A Assessment

All utilities included within the Stage 2A assessment are summaries in Table 5.3. This list has remained unchanged from the Stage 1 report because intrusive investigations which, will reveal further details of the construction and condition of the services, have yet to be undertaken. Therefore, all utilities included within the Stage 2A assessment will be taken forward to the Stage 2B assessment when the results of intrusive investigations should be available.

## Table 5.3: Summary of Utilities to Progress to Stage 2A Assessment

| Quantity | Item | Diameter | Type | Brittle/ Ductile | Location | Orientation |
|---|---|---|---|---|---|---|
| 1 | Water Main | 450mm /18” | Cast Iron | Brittle | North Circular Road | East/West |
| 1 | Water Main | 150mm /6” | Cast Iron | Brittle | North Circular Road | East/West |
| 1 | Water Main | 100mm /4” | Cast Iron | Brittle | North Circular Road | North/South |
| 1 | Combined Drainage | 900mm | Concrete | Brittle | North Circular Road | East/West |
| 1 | Combined Drainage | 600mm | Concrete | Brittle | Car Park/ Stop Box | North/South |
| 1 | Combined Drainage | 300mm | Concrete | Brittle | Car Park/ Stop Box | East/West |
| 1 | Combined Drainage | 200mm | Unknown | Unknown | Car Park/ Stop Box | North/South |
| 1 | Combined Drainage | 225mm | Unknown | Unknown | Car Park/ Stop Box | East/West |
| 1 | Combined Drainage | 300mm | Unknown | Unknown | Eccles Place/ Car Park/ Stop Box | South East/ North West |
| 1 | Combined Drainage | 300mm | Vitreous Clay | Brittle | Leo Street | North/South |
| 2 | Foul Water Sewer | Unknown | Unknown | Unknown | Mater Private | North/South |
| 2 | Surface Water Sewer | Unknown | Unknown | Unknown | Mater Private | North/South |
| 1 | Combined Drainage | Unknown | Unknown | Unknown | Leo Street | North/South |
| 1 | Brick Culvert | 480 x 440mm | Brick | Brittle | Leo Street | North/South |
| 1 | Combined Drainage | Unknown | Unknown | Unknown | Leo Avenue | East/West |
| 1 | Combined Drainage | Unknown | Unknown | Unknown | Josephine Avenue | East/West |
| 1 | Combined Drainage | Unknown | Unknown | Unknown | St Joseph Street | East/West |
| 1 | Combined Drainage | Unknown | Unknown | Unknown | Killarnery Parade | North/South |
| 1 | Fuel Tank | Unknown | Unknown | Unknown | Car Park/ Stop Box | North/South |
| 1 | Service Tunnel | Unknown | Unknown | Unknown | Car Park/ Stop Box | East/West |
| 1 | Reinforced Concrete Layer | Unknown | Reinforced Concrete | Brittle | Car Park/ Stop Box | East/West North/South |
| 2 | Unidentified Signals | Unknown | Unknown | Unknown | North Circular Road | East/West |
| 4 | Unidentified Pipes | Unknown | Unknown | Unknown | Car Park/ Stop Box | East/West |
| 5 | Unidentified Pipes | Unknown | Unknown | Unknown | Car Park/ Stop Box | North/South |
| 21 | Unidentified Signals | Unknown | Unknown | Unknown | North Circular Road | North/South |

Further details regarding services are re-produced from the Stage 1 report below.

Following a meeting between Mott MacDonald and Dublin City (Minutes of Meeting 249314 – 20/08/08; Appendix G of the Stage 1 report) Dublin City Council's main concern was a 1927 450mm Cast Iron water main running east-west down North Circular Road. This is likely to have metal to metal joints with lead seals and is likely to be in poor condition. This is a vital main supplying a large area and Dublin City Council are not willing to take any risk on this being damaged. The water main is located within the 10mm settlement contour line and as a brittle service will be progressed to Stage 2A. It is possible this pipe may need to be replaced, along the affected length, by a new HPPE pipe. This will need to be installed before construction starts. Dublin City Council would normally require the main pipe to be laid parallel to the existing one by the contractor. A 150mm cast iron main is located beneath the northern footpath of North Circular Road, running east-west. It is further from the site and not as strategically important as the 450mm, however due to it's brittle nature and location within the 10mmm contour line it is included within the Stage 2A assessment.

Combined drainage networks within the 10mm contour line are of concrete, vitreous clay or unknown construction materials. These are regarded as brittle or potentially brittle and are, therefore, included within the Stage 2A assessment. Towards the northern end of Leo Street, running north-south, is a 480mm by 440mm brick culvert. This has been specifically identified as requiring further assessment and a CCTV survey will be carried out (email dated 30/09/08 P. Doyle & C. Taylor). The culvert was previously thought to be either vitreous clay or concrete and as such is identified on the service drawing (Appendix F of the Stage 1 report) as a 450mm pipeline.

Within Mater Private Hospital foul and surface water severs run north-south linking in with the main 300mm sewer running Southeast-northwest along Eccles Place. The construction material is unknown and therefore, as these are located within the 10mm contour, are included within the Stage 2A assessment.

Private drains run north-south along the back of the Leo Street houses. These are most likely to be composed of clay and therefore brittle. Further information including plans have not yet been obtained for these drains, however as they are located within the 10mm contour and are likely to be brittle, they are included within the Stage 2A assessment.

Board Gais pipelines are located within the 10mm contour line; however these are constructed from 125mm polyethylene and 300mm ductile iron. As both these pipelines are considered ductile they are not included within the Stage 2A assessment. Following discussions with Board Gais, (Minutes of Meeting 249314 – 23/07/08; Appendix G of the Stage 1 report), Board Gais state that all their infrastructure in the Mater Grounds shall be consolidated into an energy centre and that the proposed box will not interfere with any of their services unless the dig area extends outside the box. Board Gais state that there may also be a need to protect pipes in North Circular at construction stage however Board Gais also state that this should not be a major issue.

ESB, Eircom and public lighting ducts, cables and pipes are located within the 10mm contour line; however as they are considered ductile, and are not included within the Stage 2A assessment.

Several unidentified utilities were found within North Circular Road and the proposed Stop Box. In particular two utilities were found running parallel to North Circular Road with several connections to nearby houses. As no information can be retrieved for these services and as they lie within the 10mm contour line, these are included within the Stage 2A assessment.

Towards the northern end of the proposed stop box, a large fuel tank is present. The fuel tank is overlain by a reinforced concrete layer making the precise extents and location of the tank impossible to verify. An underground service tunnel with double chamber used by a pump system that flows close to the drainage network and a ventilation box are also present beneath the reinforced concrete layer. As these will all be removed prior to construction they are not included within the Stage 2A assessment. Additional details on services can be found within the Drainage Impact Assessment, (April 2009), Report SD-2.6B (Ref 18).

## 5.5 Infrastructure included in the Stage 2A Assessment

Assessment and identification of infrastructure at risk of damage from underground excavation is subject to a performance and operation requirements. However, it is understood that to date no limiting criteria in terms of acceptable ground movements has been provided by infrastructure owners/authorities to RPA. The only exception being Iarnród Éireann who have provided limiting track geometry criteria.

The only infrastructure within the 1mm settlement contour surrounding the proposed Mater Stop excavation comprises low speed roads constructed at grade and with no significant retaining structures. As such these will be relatively tolerant of movement and only the sections of highway falling within the 10mm settlement contour at Mater are included within the Stage 2A settlement assessment. These are listed in Table 5.4 below.

**Table 5.4: Affected Infrastructure to Progress to Stage 2A**

| Name | Minimum Expected Settlement | Maximum Expected Settlement |
|---|---|---|
| Leo Street | 10mm | 25mm |
| North Circular Road | 0mm | 25mm |
| Josephine Avenue | 2mm | 20mm |
| St Joseph Street | 1mm | 20mm |
| Eccles Place | 0mm | 20mm |
| Killareny Parade | 0mm | 20mm |
| Derrynane Parade | 0mm | 20mm |

Intrusive investigations planned for the services will also reveal further details of the construction and condition of the road construction but these have yet to be undertaken. Therefore, all infrastructure included within the Stage 2A assessment will be taken forward to the Stage 2B assessment when the results of intrusive investigations will be available.

# 6 Settlement Analysis

## 6.1 General

The objective of the settlement calculations for the Stage 2A Settlement Assessment is to predict surface and sub-surface ground movement arising from the excavation of the proposed Mater Stop box. It should be noted that consideration of ground movement effects associated with the proposed tunnelling works are beyond the scope of the is report, and are not considered here. The results are presented as settlement contours and have been used within this report to identify existing buildings, structures, utilities and infrastructure that lie within the "zone of influence", as defined within the Dublin Metro North – Construction and Maintenance Requirements, (Ref. 1), and require carrying forward to the Stage 2B and or Stage 3 assessment.

In the current analysis settlement due to groundwater lowering has not been considered . This is because the assessed groundwater model (Ref 12) demonstrates that above an elevation of some 9m AOD (say 7m depth) groundwater is perched and probably contained within isolated granular pockets. Groundwater lowering will occur within the deeper regional water table within the lower glacial soils and bedrock. However, as these materials are very stiff and of low permeability it is anticipated that settlement due to groundwater lowering is likely to be small and fall within the margin of error of the conservative settlement analysis undertaken for this Stage 2A assessment.

## 6.2 References

The following documents have been used to develop the Stage 1 Settlement Assessment:

- Long. M., 2001, *'Database for Retaining Wall and Ground Movements due to Deep Excavations'* , (Ref. 4)
- CIRIA C580, 2003, *'Embedded Retaining Walls – Guidance for Economic Design'*, (Ref. 5)
- Jacobs for RPA, May 2008, *'Technical Note 12: Strategy for Assessing and Managing Building, Infrastructure and Utility Response to Ground Movements Generated by Underground Excavation'*, (Ref. 3)
- RPA, *'Dublin Metro North – Construction and Maintenance Requirements'*, (Ref. 1)
- Long, M., 2002, *'Observations of ground and structure movement during site redevelopment in Dublin'*, (Ref. 13 )
- Looby et Al., 2007. *'Deep excavations in Dublin – recent Developments', (Ref.14)*
- Mott MacDonald for RPA, November 2008, *'Mater Stop Existing Buildings and Structures Report – Stage 1: Preliminary Ground Movement Assessment'*, (Ref. 15).

## 6.3 Analytical Tools

The following analytical tools were used in this analysis:

- GRP (Ver 5.0.1) – Mott MacDonald in-house ground response programme, used to estimate greenfield ground movements.
- Surfer (Ver 8) – Used to generate settlement contours
- BREXIS (Ver 3.0.1) - Mott MacDonald in-house building response programme

## 6.4 Ground Movement Estimation Methodology

The general notation used to define ground response to excavation is as follows:

- $S_v$ is the vertical ground movement (heave defined as positive and settlement as negative) at any point.
- $S_h$ is the horizontal ground movement at any point. The horizontal ground movement has components in two orthogonal directions. The value of $\delta_h$ is the vector sum resolved into the direction of the relevant analysis section line.

There is no widely accepted method for estimating the ground movements generated by the excavation of boxes. Settlement estimation procedures have been developed based on appropriate case studies of box and shaft excavations in stiff clays; most of the limited data available relates to excavations within the London Clay.

In the procedure the settlement trough is described by the hogging zone of the Gaussian settlement trough adopted for tunnels. The following equation is used to calculate the ground surface settlements anticipated from shaft and box construction, assuming a variation of settlement from a maximum at the wall to a minimum at a distance W from the wall:

$$S_v = \delta_v e^{\left(\frac{1}{2}-\frac{1}{2}\left(1+1.5\frac{y}{W}\right)^2\right)}$$

where

$S_v$ = is the settlement from the box construction (m);

$\delta_v$ = is the settlement at the wall face (m);

y = is the distance from the box outer wall (m);

W = is the extent of the settlement trough (m).

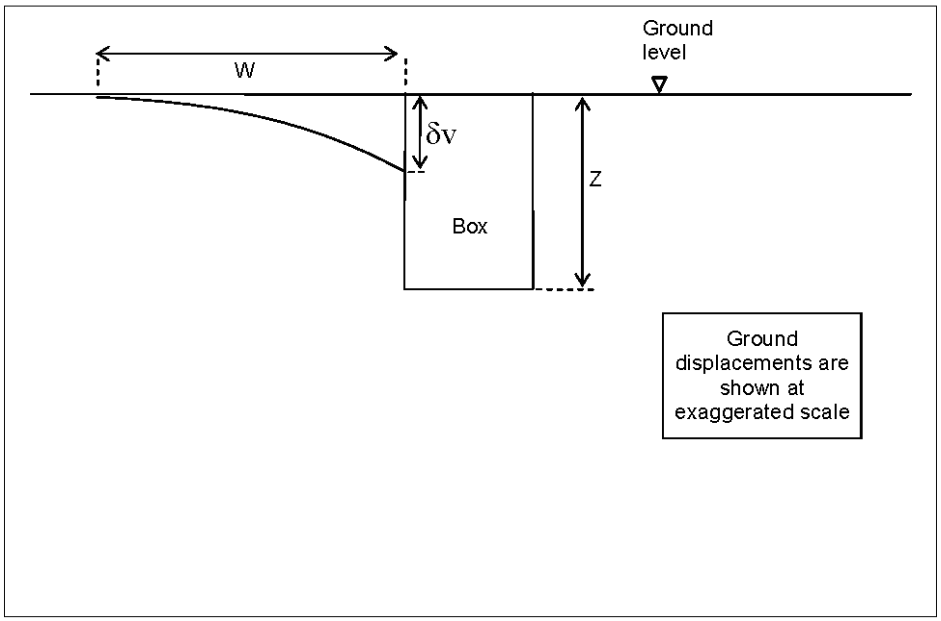
For box excavations, ground movement is dependent upon ground conditions, the depth of the excavation and support system stiffness. The values for settlement at the wall ($\delta_v$) and the extent of the settlement (W) are expressed as functions of the support stiffness and the excavation depth (Z). Figure 6.1 illustrates the assumed ground settlement profile (related to the hogging section of the normal probability curve) and input parameters for modelling box excavations.

Modelled box excavation elements are defined by the following parameters:

- 'E, N,' defines the coordinates of the start and finish of each wall element forming the box.
- 'Z' defines the excavation depth at either end of the particular wall.
- δv/Z defines the ratio of maximum settlement at the box wall to the excavation depth.
- W/Z is the ratio of settlement extent to excavation depth.
- δh/δv is the ratio of horizontal movement to vertical movement at the wall.

The predicted ground movement due to the construction of the Mater Stop box has been derived using MM in-house computer program GRP. Within the vicinity of the closed corners of the excavation, the ground settlement contours have been adjusted to allow for some superposition of movements from adjacent walls, which is beyond the scope of GRP.

**Figure 6.1: Settlement due to Box Excavation**



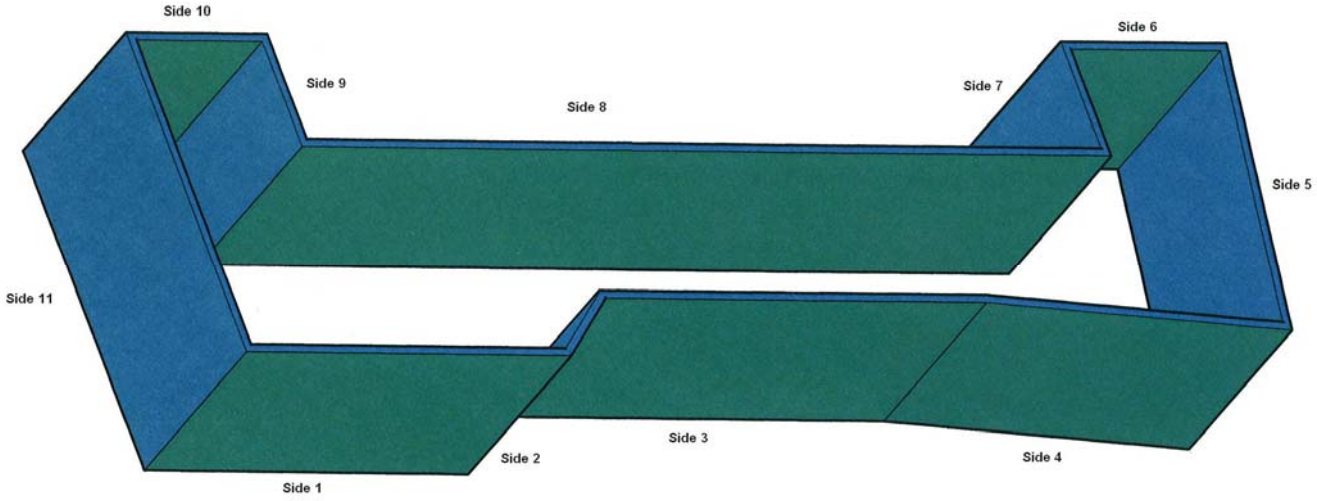
## 6.5 Modelling Assumptions

For modelling proposes the station box excavation is considered as an eleven-sided box, with the curving west wall approximated as straight, see Figure 6.2. Existing ground level at the proposed excavation site drops from approximately 17.3 mOD at the southern end of the proposed box to 14.0 mOD at the northern end. Subsequently ground level settlement estimations are prepared assuming a flat site with an inclined box, such that the excavation depth increases from 25m to 28.3m in a north to south direction. The model was located using the Metro North Grid reference system.

An overall ground level and geological sequence for the stop box was determined from borehole information from the RPA Additional Ground Investigation (Ref 16), Main Ground Investigation (Ref. 6), Preliminary Ground Investigation (Ref.7) and relevant Third Party boreholes relating to the proposed Mater Hospital. This information has been summarised in the Geotechnical Basis of Design Report, (April 2009), SD2.6iiA (Ref. 12).

The GRP output files were converted to .xls files and then exported to Surfer (ver 8). Contours were plotted for 1mm, 5mm, 10mm and 20mm increments.

**Figure 6.2: Model of eleven-sided box**




## 6.6 Input Parameters

The Mater Stop station box excavation is to be formed employing top down construction using multi-propped embedded diaphragm walls and thus classified as high support system as detailed in CIRIA C580 'Embedded Retaining Walls – Guidance for Economic Design', (Ref. 5). The majority of the case history data referred to in CIRIA C580 comes from excavations in London Clay or similar overconsolidated, sedimentary clays. The Glacial Till present at the site, often colloquially referred to as 'Dublin Boulder Clay,' is inherently stiffer than the London Clay and thus input parameter selection based purely on the information presented in CIRIA C580 is likely to lead to an over estimate of ground movements.

More reprehensive case history data is presented by Looby et Al. (2007) in *'Deep Excavations in Dublin – Recent Developments'* (Ref. 154) and shows that for a given excavation depth and support system ground movements are considerably reduced when compared the case history data presented in C580. The case histories presented by Looby et Al. (2007) confirm that a value of dv/Z of 0.1% is appropriate given the ground conditions which are anticipated and the support system to be employed.

The remaining ground movement estimation input parameters are based on engineering judgement and experience at other sites. , These being 2.5 and 1.0 for W/Z and dh/dv respectively, (Table 6.1), and are to considered conservatives given the ground conditions which are anticipated.

The adopted input parameter are summarised in Table 6.1 below.

**Table 6.1: Mater Stop Box GRP Input Parameters**

| Parameter | Value |
|---|---|
| dv/Z | 0.1% |
| W/Z | 2.5 |
| dh/dv | 1.0 |

## 6.7 Building Damage Estimation

The potential building damage assessments were undertaken using the Mott MacDonald in-house software, *BREXIS* (Building Response to Excavation Induced Subsidence). The ground movement profiles generated by GRP were imported into *BREXIS* for subsequent analysis. Buildings with shallow foundations were modelled as deep beams, the foundations being assumed to follow the anticipated greenfield surface settlement trough. The maximum tensile strain induced in the building was determined and corresponding damage category assigned through reference to the work of Burland et al. (1977), Boscardin and Cording (1989) and Burland (1995), (Ref. 19, 20 & 21), see Table 6.2.

For piled buildings the movements and corresponding strains at both founding level, i.e. the underside of pile cap, and at pile toe level were determined using *GRP* and *BREXIS*. Two cases were considered: the maximum tensile strain resulting assuming that the building has a spread foundation, and the maximum tensile strain resulting on combining the horizontal strain determined at the underside of the pile cap with the bending and diagonal strains evaluated at pile toe level. The more onerous value of maximum tensile strain was then assumed in the potential damage assessment.

**Table 6.2: BRE Digest 251 Damage Classification System**

| Category of Damage | Normal degree of severity | Limiting Tensile Strain (%) | Description of typical damage |
|---|---|---|---|
| 0 | Negligible | 0-0.05 | Hairline cracks less than about 0.1mm |
| 1 | Very Slight | 0.05-0.075 | Fine cracks not greater than 1mm which are easily treated during normal decoration |
| 2 | Slight | 0.075-0.15 | Cracks less than 5mm. Cracks filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings. |
| 3 | Moderate | 0.15-0.30 | Cracks 5-15mm, or number of cracks >3mm. The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. |
| 4 | Severe | >0.3 | Cracks 15-25mm. Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows |
| 5 | Very Severe | >0.3 | Cracks >25mm. This requires a major repair job involving partial or complete rebuilding. |

# 7 Results of Deformation Analysis

## 7.1 Existing Buildings and Structures

The assessed building movements and the degree of any anticipated damage is discussed below. The result of the Stage 2A assessment are presented in tabular form in Appendix B.

### 7.1.1 Proposed Mater Hospital Extension

The following conclusions have been drawn:-

- The maximum predicted settlement at basement level is 16mm. This occurs adjacent to the proposed Mater Stop box at for example column V, 8.5.
- The maximum slope at the proposed hospital foundation level is expected to occur adjacent to the Mater Stop box, where a slope of 1:1667 is anticipated.
- The differential movement described above is orthogonal to the column layout and the maximum differential between adjacent columns is 3.7mm over a distance of 7.2m (e.g., between columns VV, 8.5 and 9.5). This differential equates to a slope of 1:1950.

The BREXIS analysis indicates *negligible* damage from the expected excavation induced ground movements associated with the Mater Stop Box.

The hospital extension designer's have stated in Ref 10 that they are designing the structure to accommodate a maximum settlement of 25mm with a worst case differential of 8mm between column locations spaced at 7.2m centres. The results of the stage 2A assessment indicate that differential movements from the box excavation will be within these limits and the corresponding tensile strains suggest that only *negligible* damage is anticipated.

The predicted movements from the stop excavation are within these limits but the cumulative effect of movements due to the box excavation and settlement due to the building loading will need to be assessed by the building designers.

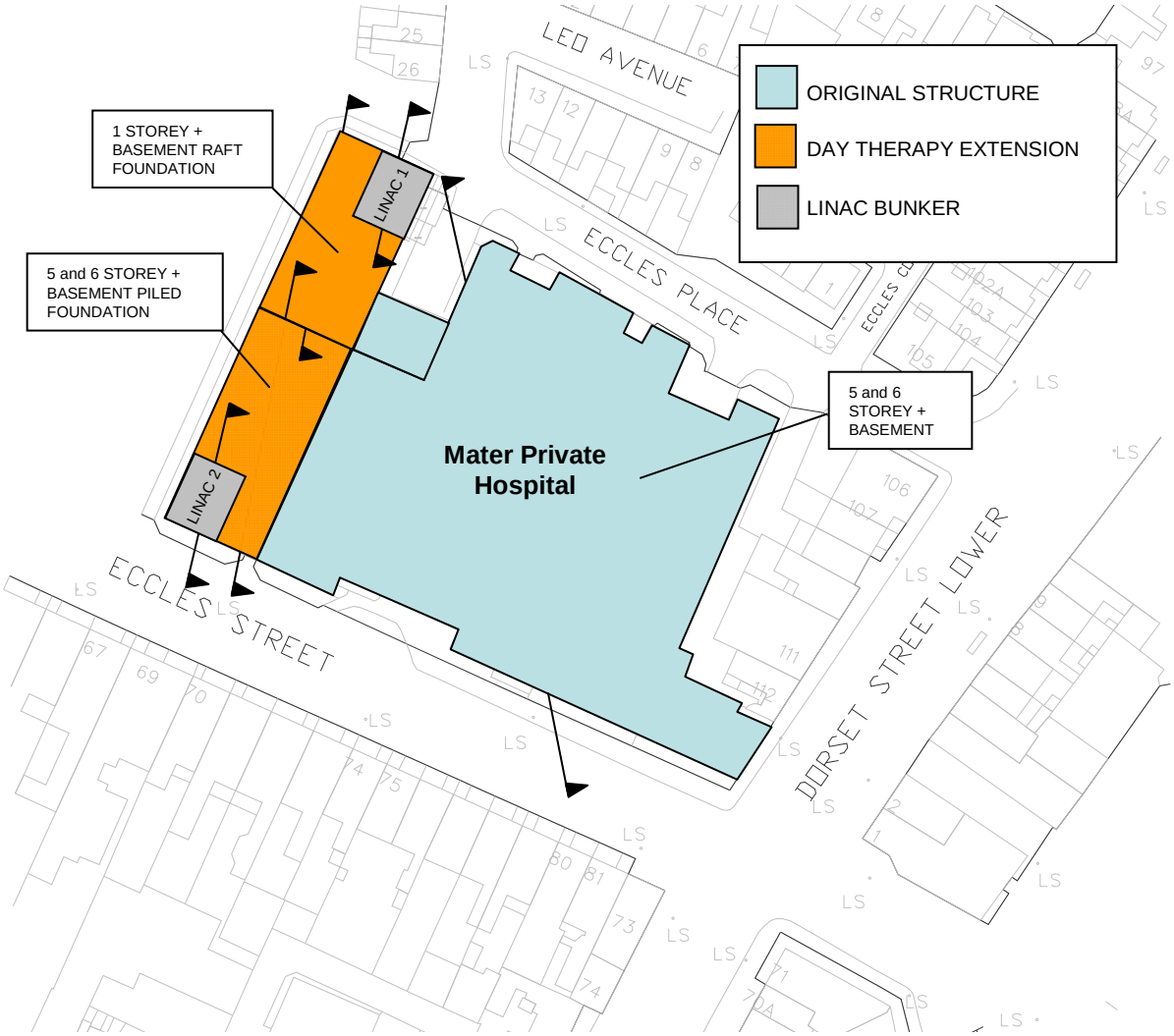
Part of the hospital extension will bear directly on the roof of the proposed Stop and a maximum settlement of 5mm has been assumed by the designers, (Ref. 11). This movement will be controlled by the structural stiffness of the stop box and the potential differential movement will need to assessed by the building designers. Dependant on the construction sequence, differential movement between that part of the extension founded on the stop box and that founded on the basement raft may also occur due to excavation of the Stop box. This aspect will also require review at Stage 2B but could be controlled by adopting adjustable bearings for the columns.

### 7.1.2 Mater Private Hospital

The Mater Private Hospital is an irregular shape occupying a site approximately 100m by 60m to the south and south west of the proposed Mater Stop Station box. To date no detailed visual survey of the hospital has been undertaken; assumptions regarding the building's age and structural form are based on the building Characterisation Survey conducted on behalf of RPA by building surveyor Jason McCann on 26th September 2007 and as-built drawings of the Day Therapy Extension constructed in the 1990s. Full details of this survey and hospital drawings are provided in Appendix A of the Stage 1 Report.

For assessment purposes 5 specific sections of the hospital building have been considered, Figure 7.1, refers.

**Figure 7.1: Mater Private Hospital - Sections considered during potential damage assessment**



**Main Portion of the Hospital**

Based on the survey the main portion of the hospital was thought to have been constructed in around the 1980's. The building is constructed from concrete with a steel frame. The nature and depth of the foundations for the main portion of the hospital building is unknown. The survey states that the building is likely to be supported on concrete piles, however in the absence of information the potential damage assessment has been undertaken assuming the building rests on a shallow foundation 3.1 mbgl existing ground level, a conservative assumption within the vicinity of an open excavation. The building is approximately 20m high. The structural form of the basement is unknown; however it is likely to be constructed from concrete.

The BREXIS analysis indicates *negligible* damage is expected to this part of the hospital, with a maximum settlement of 13mm anticipated adjacent to Eccles Place.

**Day Therapy Extension**

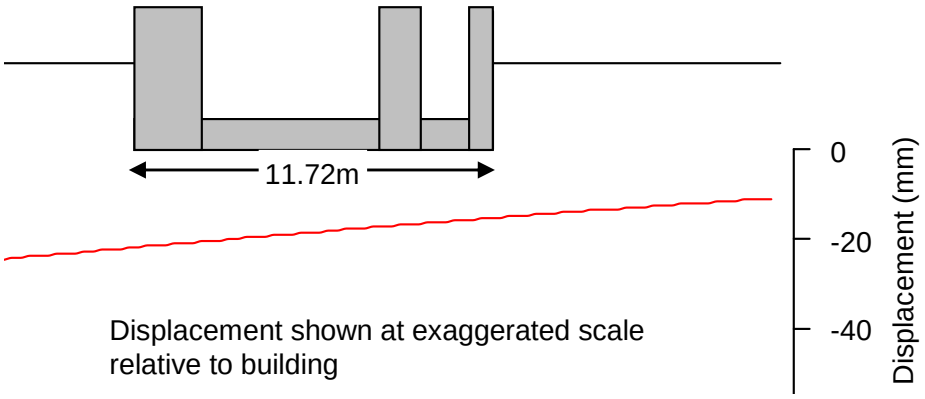
The Day Therapy extension of Mater Private Hospital was construction in the 1990s and is a regular shaped 1 and 5 storey structure that abuts the main portion of the hospital along it's western wall. The extension is a masonry clad concrete framed building, partially founded on piles. The Day Therapy Extension has single basement along it length with the LIN-AC 1 bunker situated in the basement's north eastern corner and the LIN-AC 2 bunker situated in the south western corner. For assessment purposes the Day Therapy extension is considered as four structures with the 1 storey, 5 storey portions and each LINAC bunker being assessed separately.

The 1 storey portion of the Day Therapy extension is an approximate rectangle of 17m by 21m, with a basement. This portion of the building is considered to rest upon a raft foundation with a depth of approximately 3.1 mbgl existing ground level. The BREXIS analysis indicates negligible damage is expected to this part of the hospital, with a maximum settlement of 23mm anticipated adjacent to the proposed Mater Stop Station box.

The 5 storey portion of the Day Therapy extension is approximately rectangular in shape, 17m by 37m, with a basement. This portion of the building is considered to be founded upon piled foundations, a uniform pile toe depth of 10mbgl with the pile cap at 3.1mbgl has been assumed. BREXIS analysis indicates negligible damage is expected to this part of the hospital, with a maximum settlement of 6mm anticipated at pile toe level.

The LIN-AC bunkers house movement sensitive LinAcc equipment. Each bunker has approximate rectangular dimensions of 12m by 10m and is formed with very thick discrete reinforced concrete walls and roof slab with a thin ground bearing, independent floor slab. Anticipated Settlement across LIN-AC 1, as shown in Figure 7.2, is 22mm below the northern reinforced concrete wall reducing to 15mm below the southernmost reinforced wall. For LIN-AC 2mm of settlement is anticipated below the northern reinforced concrete wall and 1mm below the southern reinforced concrete wall. BREXIS analysis indicates negligible damage to the structure of both bunkers is expected. However, a full assessment of the affect of the anticipated ground movement on the sensitive LinAcc equipment will need to be undertaken. An assessment will also need to be undertaken of the likely effects of differential movement between elements of the building supported by different foundation systems.

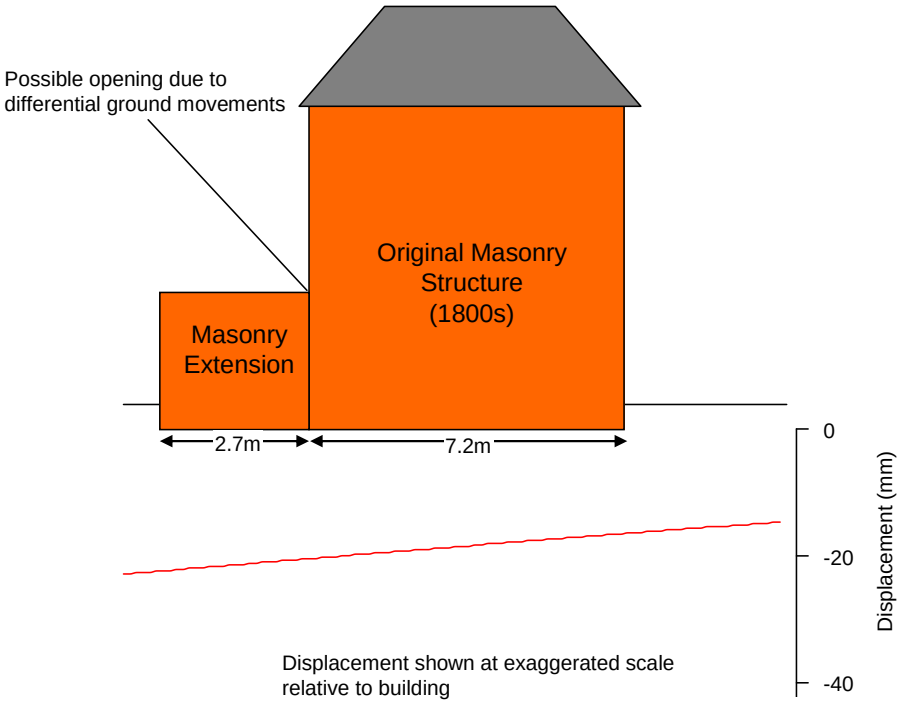
**Figure 7.2: Foundation Settlement Level Across LIN-AC 1, north to south**




### 7.1.3 Leo Street Properties

The maximum anticipated tensile strains for the Leo Street properties Nos. 3 -21 suggest that only *negligible* damage due ground movements associated with the proposed Mater Stop Box excavation will occur, see Table 6.2. However, a typical Leo Street property consists of both the original two storey 1800s masonry structure and a more recent extension at the rear of the property. The interface between the original structure and the extension could be susceptible to some cracking and 'opening up' as the buildings are in essence two abutting masonry structures that will respond separately to excavation induced ground movement. Figure 7.3 presents the anticipate foundation level settlement across a typical cross-section of one of the Leo Street properties however the amount of movement is likely to depend on individual extension construction.

**Figure 7.3: Foundation Level Settlement across typical Leo Street Property**




Nos. 1-2 and Nos. 22-24 Leo Street are situated with the direct vicinity of closed corners of the proposed Mater Stop Excavation. Within the vicinity of the closed corners there will be a superposition of ground movements from the adjoining walls of the excavation. It is acknowledge that modelling limitations of the closed corner movements within GRP mean that this superposition is not considered; consequently no BREXIS assessment for these 4 properties has been presented. It is expected that will be *very slight* to *slight* and may require further assessment.

Under the circumstances described above it is unlikely that localised damage will exceed the *slight* to *moderate* threshold for the Leo Street properties. However it is recommended that the potential damage to Leo Street properties is reviewed at Stage 2B assessment once the nature of the building foundations is ascertained and the nature of any existing building damage is clarified. It is recommended that 2 & 21 Leo Street also undergo a full Building Characterisation Survey (as detailed in Appendix C) to review the nature and extend of the existing building damage.

### 7.1.4 North Circular Road Properties

The calculated maximum tensile strains indicate that none of the assessed properties are likely to experience damage levels exceeding the negligible threshold.

### 7.1.5 Other Properties

The calculated maximum tensile strains indicate that none of the assessed properties are likely to experience damage levels exceeding the negligible threshold.

## 7.2 Existing Utilities

At the time of preparing this report RPA are in the process of undertaking a slit trench survey to obtain further information on the nature and condition of the existing services. As the results of this investigation are not yet available the criteria adopted in the Stage 1 Report, for the identification of services requiring treatment and/or further assessment remain unchanged. These criteria are a maximum settlement of 50mm for ductile services and 10mm for brittle.

As the maximum anticipated surface settlement is 28mm only brittle services, as identified in Section 5.4 of this report, are considered in the Stage 2A assessment. These primarily comprise drainage or sewer pipes and the Drainage Impact Assessment Report, (April 2009), SD-2.6B, (Ref 18) has considered the impact of deformation on all drainage utilities within the 10mm settlement contour.

The Drainage Impact Assessment Report recommends that combined drainage services in North Circular Road and Leo Street be subject to a CCTV survey before being lined with a structural liner prior to excavation of the box. All other drainage services which are not to be abandoned are to be subject to CCTV surveys before and after the construction works. Reference 18 should be consulted for further details.

As there will be considerably more information available after the slit trench and CCTV surveys have been undertaken it is recommended that all utilities within the 10mm settlement contour be further reviewed during the Stage 2B assessment. This will allow for any necessary further discussion to be held with individual utility owners to establish whether the predicted ground movements will place their assets at risk of damage.

## 7.3 Existing Infrastructure

The infrastructure considered in the Stage 2A assessment (see section 5.5 of this report) comprises low speed roads. The maximum anticipated surface ground slope due to the box excavation is 10mm in a distance of 20m i.e., 1:2000 and it is not considered that this would cause any significant damage to a well maintained flexible highway. On this basis none of the existing infrastructure within the zone of influence require a Stage 3 assessment.

# 8 Conclusions

The results of the Stage 2A re-assessment of ground deformation due to excavation of the stop box have produced results very similar to the Stage 1, preliminary assessment. The maximum predicted surface settlement is 29mm although as this occurs immediately adjacent to the box actual values are likely to be less due friction between the diaphragm wall and the surrounding soil. The "zone of influence" of the construction works which is defined as the 1mm contour extends for a maximum of 80mm from the box.

The Mater Private Hospital is located at the south-east corner of the proposed Mater Stop box excavation. The BREXIS analysis indicates a maximum settlement of 23mm for the corner of the 1 storey extension closest to the box reducing to 6mm for the main 5 storey section of the building. The calculated maximum tensile strains indicate that damage levels will not exceed the negligible category anywhere within the hospital. However, as this is a sensitive structure it is recommended that a Stage 3 assessment be undertaken to more closely look at differential movement between elements of the structure founded on different foundation systems.

The Mater Campus Hospital Development (MCHD) will be located immediately to the west of the box excavation and will also be partly supported by the roof of the completed box. The maximum calculated settlement at basement (founding) level of MCHD is 16mm and the BREXIS analysis indicates maximum tensile strains that would equate to damage levels within the negligible category. However, as this is a sensitive structure it is recommended that a Stage 2B assessment be undertaken to more closely look at building deformation. The building designer will also need to consider the potential for differential movement between elements of the structure founded adjacent to and upon the box.

A large number of domestic properties have been assessed within the 10mm settlement contour. The BREXIS analysis has indicated maximum tensile strains that would equate to damage levels within the negligible category for all of the properties. A large number of the properties in Leo Street have single and in one case two, storey extensions at the rear. There is probably little structural connectivity between the two building elements which are also likely to be founded differently. RPA will be undertaking trial excavations to investigate the foundations. Although current analysis indicates that damage levels at the interface between the extension and the house are unlikely to exceed the *slight to moderate* category this aspect should be re-assessed in the Stage 2B assessment when the results of the trial excavations and condition surveys are available.

The only existing utilities currently giving rise for concern are the combined drainage runs in North Circular Road and Leo Street where recommendations have been made in the Drainage Impact Assessment Report for structural re-lining. All other services are to be subject to CCTV survey and the results of these should be reviewed in the Stage 2B assessment.

None of the existing highway infrastructure within the zone of construction influence is likely to suffer significant damage due to ground movements.

# 9 References

1. RPA. Dublin Metro North – Construction and Maintenance Requirements. Report Ref: MN-400_MTr_0003_10

2. Jacobs for RPA. (May 2008). Dublin Metro North Stage 1 Preliminary Ground Movement Assessment Report. Report No. B0307000-010/STB.061/004/2.

3. Jacobs for RPA. (May 2008). Technical Note 12: Strategy for Assessing and Managing Building, Infrastructure and Utility Response to Ground Movements Generated by Underground Excavation.

4. Long. M. (2001). *Database for Retaining Wall and Ground Movements due to Deep Excavations.*

5. CIRIA C580. (2003). *'Embedded Retaining Walls – Guidance for Economic Design.*

6. Norwest Holst Soil Engineering Ltd. (January 2008). Report on a Ground Investigation at Dublin Metro North, Main Ground Investigation – Sections 6 & 7. Report Ref: F14824/F01.

7. Irish Geotechnical Services Ltd (IGSL). (March 2007). Dublin Metro North Ground Investigation, Factual Ground Investigation Report (Volume 1). RPA Contract M7081. Report No. 03/11826/March 07.

8. Mott MacDonald for RPA. (September 2008). Mater Stop Preliminary Geotechnical Report. Report No. M00384/243231/ID-1-6/A.

9. Attewell, P.B., Yeates, J. & Selby, A.R. (1986). Soil movements induced by tunnelling and their effects on pipelines and structures. 1st Edition, Blackie, Glasgow.

10. TST Engineering Ltd. (November 2007). Technical Report Underground Mapping Project Metro North. Report No. TR/1018/2007

11. Arup Consulting Engineers. (June 2008). Mater Campus Hospital Development. Mater Hospital. Basis of Design Report. Report No. D 5491/100

12. Mott MacDonald for RPA. (April 2009). Mater Stop Geotechnical Basis of Design Report. Report No. M000384/243231/SD-2.6Aii/A

13. Long, M. 2002. Observations of ground and structure movement during site redevelopment in Dublin. *Geotechnical Engineering.* Vol 155, issue 4, pp 229-242.

14. Looby M. & Long, M. 2007. Deep Excavations in Dublin Recent Developments. Paper first presented to a meeting of the Geotechnical Society of Ireland at Engineers Ireland, 22 Clyde Rd, Dublin 4, on 11th December

15. Mott MacDonald for RPA. (November 2008). Mater Stop Existing Buildings and Structures Report. Stage 1: Preliminary Ground Movement Assessment. Report No. M000384/243231/ID1.6E/B

16. Norwest Holst Soil Engineering Ltd (March 2009) Report on a Ground Investigation for Mater Stop – Additional GI, Dublin. Report Ref F15404/F01

17. Jacobs for RPA. (May 2008). Dublin Metro North Stage 2A Preliminary Building Response Assessment Report, Rev. 1. Report No. B0307000-010/STB.061/004/2.

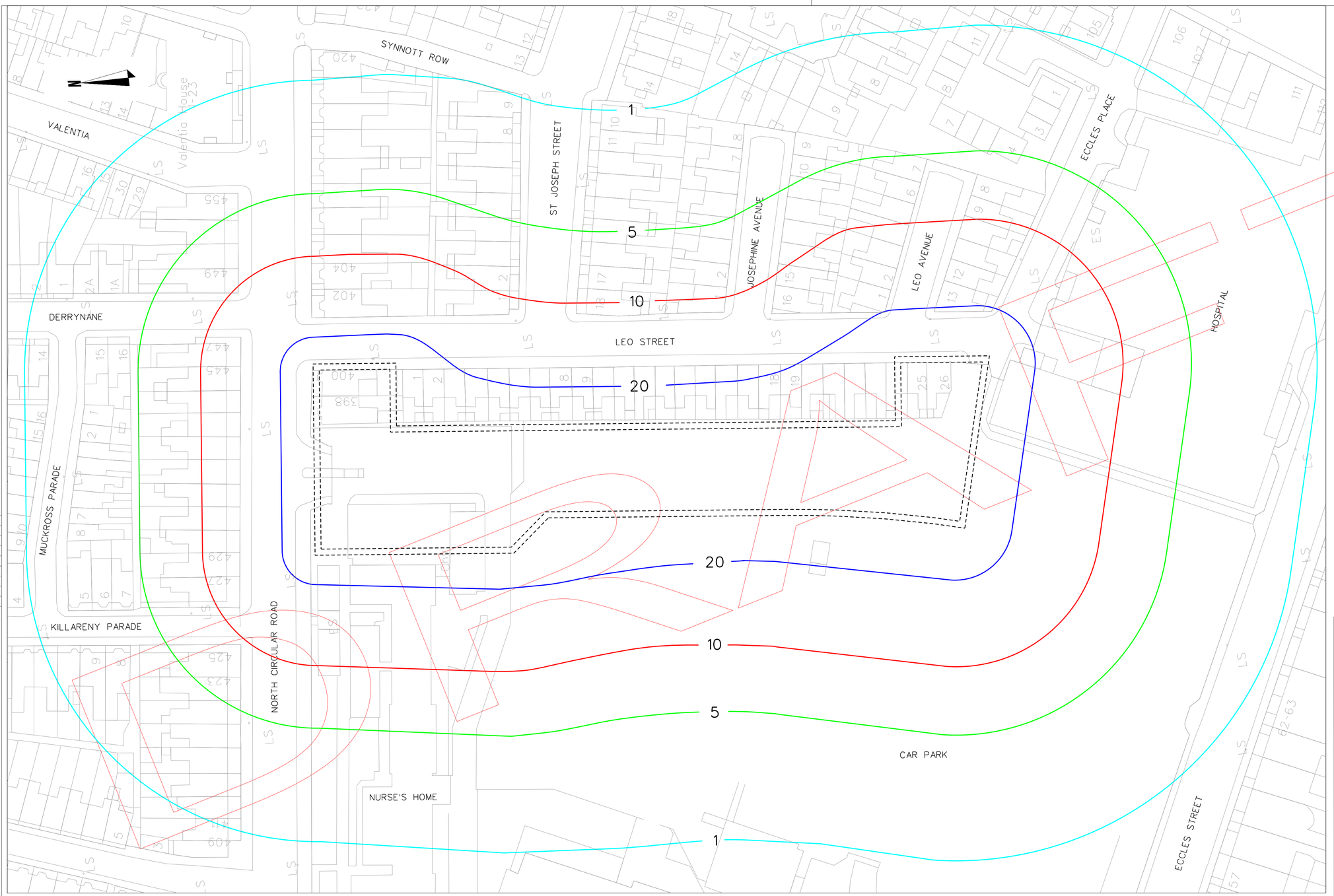
18. Mott MacDonald for RPA, (April 2009). Mater Stop Drainage Impact assessment Report. Report No. M00384/243231/SD-2.6B/A.

19. Burland, J.B., Broms, B.B. and de Mello, V.F. (1977). State of the Art Report: Behaviour of foundations and structures. Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, 1977. Volume 2, pp 495-546

20. Boscardin, M.D. and Cording, E.J. (1989). Building response to excavation-induced settlement. Proceedings of the American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 115, No.1, paper 23066, pp1-21, January 1989

21. Burland, J.B. (1995). Assessment of risk of damage to buildings due to tunnelling and excavations. Invited Special Lecture to IS-Tokyo '95: 1st International Conference on Earthquake Geotechnical Engineering, Proceedings 1st International Conference on Earthquake Geotechnical Engineering, Ishihara (Ed.), pp 1189-1201, Balkema: Rotterdam, 1997.

# Appendix A Predicted Settlement Contour Drawings

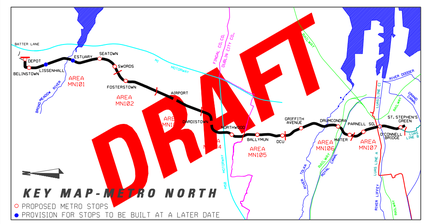



P L A N

## NOTES:

1. ORDNANCE SURVEY MAPPING BASE USED AS RPA MAPPING DOES NOT COVER A SUFFICIENTLY LARGE AREA.

| REV | DATE | DESCRIPTION | BY | CHK | APD |
|---|---|---|---|---|---|
| D01 | 09.04.09 | SCHEME DESIGN - STAGE 2 | KeT | LNP | MSA |

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METRO

Mott MacDonald

| CONTRACT NO | AREA | CHAINAGE |
|---|---|---|
| MN-7091 | MN_106 | |

LOCATION
MATER STOP

DRAWING TITLE
PREDICTED SETTLEMENT CONTOURS
SURFACE LEVEL

| | | |
|---|---|---|
| PREPARED: K e TIBBS | DESIGNED BY C E TAYLOR | APPROVED BY M S AKBAR |
| CHECKED C E TAYLOR | CHECKED L N PARRY | AS BUILT BY |
| DATE: 09.04.09 | SCALES: 1:500 @ A1 | SHEET SIZE A1 |

| STAGE | LINE | CONTRACT | ELEMENT | DRW NO | DRW REV |
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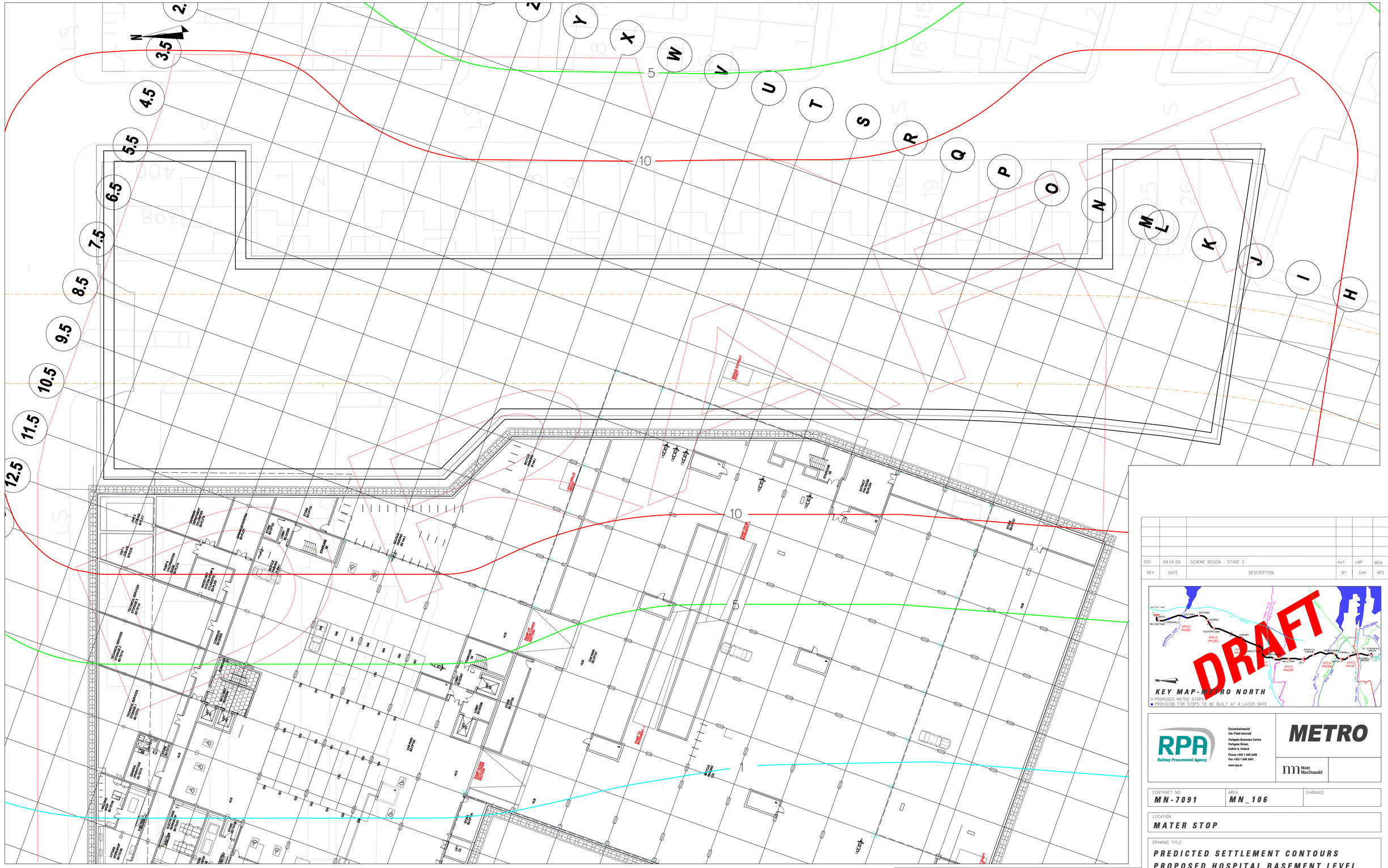


| REV | DATE | DESCRIPTION | BY | CHK | APD |
|---|---|---|---|---|---|
| D01 | 09.04.09 | SCHEME DESIGN - STAGE 2 | Kef | LNP | MSA |




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Mott MacDonald

METRO

| CONTRACT NO | AREA | CHAINAGE |
|---|---|---|
| MN-7091 | MN_106 | |

LOCATION: MATER STOP

DRAWING TITLE: PREDICTED SETTLEMENT CONTOURS PROPOSED HOSPITAL BASEMENT LEVEL

| | | | |
|---|---|---|---|
| PREPARED: K e TIBBS | DESIGNED BY C E TAYLOR | APPROVED BY M S AKBAR | |
| CHECKED C E TAYLOR | CHECKED L N PARRY | AS BUILT BY | |
| DATE: 09.04.09 | SCALES: 1:250 @ A1 | SHEET SIZE A1 | |

| STAGE | LINE | CONTRACT | ELEMENT | DRW NO | DRW REV |
|---|---|---|---|---|---|
| D | MN | 7091 | GI | 6009 | D01 |

## NOTES:

1. ORDNANCE SURVEY MAPPING BASE USED AS RPA MAPPING DOES NOT COVER A SUFFICIENTLY LARGE AREA
2. MATER HOSPITAL GRID DOES NOT MATCH EITHER RPA OR OS GRIDS AND HAS BEEN MANUALLY ADJUSTED TO CREATE A BEST FIT

# Appendix B Results of Stage 2A Building Assessments

| Buildings | | Maximum Predicted Ground Scope (mm) | Maximum Predicted Settlement (mm) | Maximum Horizontal Movement (mm) | Maximum Tensile Strain (%) | Potential Damage Category | Existing Damage Category | Notes |
|---|---|---|---|---|---|---|---|---|
| No. | Street Name | | | | | | | |
| 1&2 | Leo Street | Building in direct vicinity of closed corner of excavation. | | | | | 3 | |
| 3 | Leo Street | 1:1667 | 20 | 24 | 0.028 | Negligible | 2 | |
| 4 | Leo Street | 1:1667 | 22 | 26 | 0.026 | Negligible | - | |
| 5 | Leo Street | 1:1667 | 20 | 24 | 0.028 | Negligible | 1 | |
| 6 | Leo Street | 1:1667 | 20 | 24 | 0.028 | Negligible | - | |
| 7 | Leo Street | 1:1667 | 21 | 25 | 0.028 | Negligible | 2 | |
| 8 | Leo Street | 1:1667 | 21 | 25 | 0.028 | Negligible | - | |
| 9 | Leo Street | 1:1667 | 21 | 25 | 0.028 | Negligible | 2 | |
| 10 | Leo Street | 1:1667 | 21 | 25 | 0.028 | Negligible | - | |
| 11 | Leo Street | 1:1667 | 21 | 25 | 0.028 | Negligible | 2 | |
| 12 | Leo Street | 1:1667 | 21 | 25 | 0.027 | Negligible | - | |
| 13 | Leo Street | 1:1667 | 21 | 25 | 0.028 | Negligible | 2 | |
| 14 | Leo Street | 1:1667 | 21 | 25 | 0.027 | Negligible | - | |
| 15 | Leo Street | 1:1667 | 21 | 25 | 0.027 | Negligible | 2 | |
| 16 | Leo Street | 1:1667 | 22 | 26 | 0.027 | Negligible | - | |
| 17 | Leo Street | 1:1667 | 22 | 26 | 0.027 | Negligible | 2 | |
| 18 | Leo Street | 1:1667 | 22 | 26 | 0.027 | Negligible | - | |
| 19 | Leo Street | 1:1667 | 22 | 26 | 0.027 | Negligible | 2 | |
| 20 | Leo Street | 1:1667 | 22 | 26 | 0.027 | Negligible | - | |
| 21 | Leo Street | 1:1667 | 22 | 26 | 0.027 | Negligible | 3 | |
| 22 | Leo Street | Building in direct vicinity of closed corner of excavation. | | | | | - | |
| 23 | Leo Street | Building in direct vicinity of closed corner of excavation. | | | | | 1 | |
| 1 | Leo Avenue | 1:1667 | 19 | 25 | 0.032 | Negligible | - | |
| 2 | Leo Avenue | 1:1667 | 17 | 23 | 0.038 | Negligible | - | |
| 3 | Leo Avenue | 1:1667 | 14 | 21 | 0.042 | Negligible | - | |
| 4 | Leo Avenue | 1:1667 | 12 | 19 | 0.043 | Negligible | - | |
| 10 | Leo Avenue | 1:1667 | 12 | 19 | 0.044 | Negligible | - | |
| 11 | Leo Avenue | 1:1667 | 14 | 22 | 0.043 | Negligible | - | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12 | Leo Avenue | 1:1667 | 17 | 23 | 0.039 | Negligible | - | |
| 13 | Leo Avenue | 1:1667 | 20 | 26 | 0.033 | Negligible | - | |
| 1 | Josephine Avenue | 1:1667 | 11 | 18 | 0.044 | Negligible | - | |
| 13 | Josephine Avenue | 1:2500 | 9 | 16 | 0.043 | Negligible | - | |
| 14 | Josephine Avenue | 1:2172 | 10 | 18 | 0.043 | Negligible | - | |
| 15 | Josephine Avenue | 1:1667 | 11 | 19 | 0.044 | Negligible | - | |
| 16 | Josephine Avenue | 1:1667 | 14 | 20 | 0.037 | Negligible | - | |
| 1 | St Joseph Street | 1:1667 | 13 | 19 | 0.043 | Negligible | - | |
| 2 | St Joseph Street | 1:2100 | 10 | 16 | 0.043 | Negligible | - | |
| 3 | St Joseph Street | 1:2301 | 8 | 14 | 0.040 | Negligible | - | |
| 18 | St Joseph Street | 1:1667 | 11 | 18 | 0.044 | Negligible | - | |
| 402 | North Circular Road | 1:1667 | 17 | 22 | 0.036 | Negligible | - | |
| 404 | North Circular Road | 1:1667 | 13 | 20 | 0.043 | Negligible | - | |
| 406 | North Circular Road | 1:1667 | 10 | 17 | 0.044 | Negligible | - | |
| 425 | North Circular Road | 1:2500 | 7 | 13 | 0.040 | Negligible | - | |
| 427 | North Circular Road | 1:2500 | 11 | 18 | 0.045 | Negligible | - | |
| 429 | North Circular Road | 1:1667 | 12 | 18 | 0.044 | Negligible | - | |
| 431 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 433 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 435 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 437 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 439 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 441 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 443 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 445 | North Circular Road | 1:1667 | 12 | 18 | 0.045 | Negligible | - | |
| 445 | North Circular Road | 1:1667 | 12 | 18 | 0.044 | Negligible | - | |
| 449 | North Circular Road | 1:2500 | 8 | 15 | 0.043 | Negligible | | |
| 451 | North Circular Road | 1:2500 | 7 | 13 | 0.041 | Negligible | | |

| Buildings | | Maximum Predicted Ground Scope (mm) | Maximum Predicted Settlement (mm) | Maximum Horizontal Movement (mm) | Maximum Tensile Strain (%) | Potential Damage Category | Existing Damage Category | Notes |
|---|---|---|---|---|---|---|---|---|
| No. | Street Name | | | | | | | |
| Mater Private Hospital | | | | | | | | LIN-AC bunkers contain sensitive Lin - Acc equipment. Detail assessment at Stage 3 is recommended. |
| Original Structure | | 1:1667 | 13 | 20 | 0.030 | Negligible | - | |
| Day Therapy Extension 1 Storey (Raft Foundation) | | 1:1667 | 23 | 25 | 0.032 | Negligible | - | |
| Day Therapy Extension 5 & 6 Storey | Raft Assessment | 1:1667 | 11 | 18 | 0.034 | Negligible | - | |
| | Piled Assessment | 1:2500 | 6 | 10 | 0.034 | Negligible | - | |
| LIN-AC 1 | | 1:1667 | 22 | 25 | 0.028 | Negligible | - | |
| LIN-AC 2 | | 1:2500 | 2 | 5 | 0.021 | Negligible | - | |
| Children's Hospital | | | | | | | | |
| Proposed Extension | | 1:1667 | 16 | 18 | 0.032 | Negligible | - | |

# Appendix C RPA Recommended for Building Characterisation Survey

## Table C.1: RPA Recommended for Building Characterisation Survey

| Survey No. | Building Identification | Street | Remarks | Full/ Validation | Survey Type Required, (Type A, Type B or Record Search) |
|---|---|---|---|---|---|
| | **Mater Stop, Leo Street** | | | | |
| 2 | No. 23 | Leo Street | Mater Stop enabling works | Full | B |
| 3 | No. 18 | Leo Street | Mater Stop enabling works | Full | B |
| 4 | No. 13 | Leo Street | Mater Stop enabling works | Full | B |
| 5 | No. 8 | Leo Street | Mater Stop enabling works | Full | B |
| 6 | No. 3 | Leo Street | Mater Stop enabling works | Full | B |
| 7 | No. 1 | Leo Street | Mater Stop enabling works | Full | B |
| | | | | | |
| | **Mater Stop, Eccles Street (South side walking west)** | | | | |
| 8 | No. 71 | Eccles Street | Mater Stop enabling works | Full | B |
| 9 | No. 70 | Eccles Street | Mater Stop enabling works | Full | B |
| 10 | No. 69 | Eccles Street | Mater Stop enabling works | Full | B |
| 11 | No.67 | Eccles Street | Mater Stop enabling works | Full | B |
| 12 | No.66 | Eccles Street | Mater Stop enabling works | Full | B |
| 13 | No. 65 | Eccles Street | Mater Stop enabling works | Full | B |
| 14 | No. 64 | Eccles Street | Mater Stop enabling works | Full | B |
| 15 | No. 63 | Eccles Street | Mater Stop enabling works | Full | B |
| 16 | No. 62 | Eccles Street | Mater Stop enabling works | Full | B |
| 17 | No. 61 | Eccles Street | Mater Stop enabling works | Full | B |
| 18 | No. 60 | Eccles Street | Mater Stop enabling works | Full | B |
| | | | | | |

| Survey No. | Building Identification | Street | Remarks | Full/ Validation | Survey Type Required, (Type A, Type B or Record Search) |
|---|---|---|---|---|---|
| | **Eccles Street** | | | | |
| 19 | Mater Private Hospital | Eccles Street | Mater Stop enabling works | Full | B |
| | | | | | |
| | **North Circular Road (north side of road)** | | | | |
| 20 | No. 427 | North Circular Road | Mater Stop enabling works | Full | B |
| 21 | No. 429 | North Circular Road | Mater Stop enabling works | Full | B |
| 22 | No. 431 | North Circular Road | Mater Stop enabling works | Full | B |
| 23 | No. 433 | North Circular Road | Mater Stop enabling works | Full | B |
| 24 | No. 435 | North Circular Road | Mater Stop enabling works | Full | B |
| 25 | No. 437 | North Circular Road | Mater Stop enabling works | Full | B |
| 26 | No. 439 | North Circular Road | Mater Stop enabling works | Full | B |
| 27 | No. 441 | North Circular Road | Mater Stop enabling works | Full | B |
| 28 | No. 443 | North Circular Road | Mater Stop enabling works | Full | B |
| 29 | No. 445 | North Circular Road | Mater Stop enabling works | Full | B |
| 30 | No. 457 | North Circular Road | Mater Stop enabling works | Full | B |
| | | | | | |
| 31 | No. 12 | Eccles Place | Mater Stop enabling works | Full | B |
| 32 | No. 2 | Leo Avenue | Mater Stop enabling works | Full | B |
| 33 | No. 15 | Josephine Avenue | Mater Stop enabling works | Full | B |
| 34 | No. 2 | Josephine Avenue | Mater Stop enabling works | Full | B |
| 35 | No. 18 | Joseph Street | Mater Stop enabling works | Full | B |
| 36 | No. 1 | Joseph Street | Mater Stop enabling works | Full | B |
| 37 | No. 402 | North Circular Road | Mater Stop enabling works | Full | B |

Details of information to be collected during Type B Survey are presented below in Table C.2.

**Table C.2: Type B Survey: Information to be collected to assist in the assessment of the impact of ground movements and vibration**

| Information to be collected | Details |
|---|---|
| General Building Details | ▪ Address.<br>▪ Plan showing location and extent of property.<br>▪ Confirm building footprint correlates with OS plan footprint or provide drawing showing differences with dimensions.<br>▪ Name of building owner or representative, and contact details.<br>▪ Name of person spoken to at time of survey. If name unavailable persons relationship to the owner of the property.<br>▪ Building use - residential / office / retail / etc<br>▪ Photographs of building cross referenced to location plans, sketches or drawings so it clearly can be ascertained where property viewed from.<br>▪ Age of building.<br>▪ Approximate dimensions of building (plan and height above ground).<br>▪ Confirm existence of basement<br>▪ Form of construction<br>▪ Number of floors and form of construction to support floor(s)<br>▪ Foundation type<br>▪ General building condition (view on likely damage susceptibility / evidence of past foundation settlement / type and age of significant defects); Categorise in accordance with BRE 251 (1990) Damage Classification<br>▪ Where condition of structure is variable highlight areas of particular poor condition.<br>▪ Comments (i.e. any major reconstruction / any features of the building which may render the building sensitive to ground movement).<br>▪ Evidence of extensions including age, form of construction, form of connection to main building, extension foundations and approximate extension dimensions.<br>▪ Details of other structures in relation to property i.e. walls, garages, out house etc. Information to include description, photographs, age, location (shown on plan), dimensions, condition (including identification of any areas of particular poor condition), form of construction, foundations, and particular features that may render it susceptible to ground movements. |

<table>
<tr><th>Information to be collected</th><th>Details</th></tr>
<tr><td colspan="2"><u>Basement Details</u></td></tr>
<tr><td>Photographic Record</td><td>▪ External and internal of basement.<br>▪ Photographs cross referenced to drawings so it can be clearly ascertained where viewed from.</td></tr>
<tr><td>Location</td><td>▪ Referenced to project grid to enable location of basement to be accurately placed on plans relative to DMN works.</td></tr>
<tr><td>Age of Structure</td><td>▪ Included in 1. above.</td></tr>
<tr><td>Dimensional Survey</td><td>▪ Plan and height - Internal and external (where possible)<br>▪ Distance basement extends beyond façade(s)<br>▪ Levels of basement floor slab, soffit and ground level above.<br>▪ Drawings to illustrate location, dimensions, and any other principal features.</td></tr>
<tr><td>Condition</td><td>▪ Commentary on condition.<br>▪ Location and description of significant defects with location cross referenced to drawings.<br>▪ Categorise in accordance with BRE 251 (1990) Damage Classification</td></tr>
<tr><td>Basement Structural Details</td><td>▪ Basement freestanding or supporting building façade.<br>▪ Form of construction.<br>▪ Evidence / details of structural modifications.</td></tr>
<tr><td><u>Historical Records</u></td><td>Undertake search of historical records. This shall include search of the institutions and organisations identified below:
<table>
<tr><th>Institution / Organisation Name</th><th>Address</th></tr>
<tr><td>Dublin City Council Building Control Office</td><td>Dublin City Council, Civic Offices, Wood Quay, Dublin 8.</td></tr>
<tr><td>Dublin City Library and Archive</td><td>138 - 144 Pearse Street, Dublin 2.</td></tr>
<tr><td>Office of Public Works</td><td>51 St. Stephen's Green, Dublin 2.</td></tr>
<tr><td>The National Archives</td><td>Bishop Street, Dublin 8.</td></tr>
<tr><td>Irish Architectural Archive</td><td>45 Merrion Square, Dublin 2.</td></tr>
<tr><td>National College of Ireland</td><td>National College of Ireland, Mayor Street, Dublin 1.</td></tr>
</table>
▪ As built information<br>▪ Enquire and obtain records from building owner or representative.<br>Provided copies of relevant information found.</td></tr>
</table>

<table>
<tr><th>Information to be collected</th><th>Details</th></tr>
<tr><td></td><td>

**BRE 251 (1990) Damage Classification**

<table>
<tr><th>Category of damage</th><th>Normal degree of severity</th><th>Limiting Tensile Strain (%)</th><th>Description of typical damage</th></tr>
<tr><td>0</td><td>Negligible</td><td>0 – 0.05</td><td>Hairline cracks less than about 0.1mm</td></tr>
<tr><td>1</td><td>Very Slight</td><td>0.05 – 0.075</td><td>Fine cracks not greater than 1mm which are easily treated during normal decoration.</td></tr>
<tr><td>2</td><td>Slight</td><td>0.075 – 0.15</td><td>Cracks less than 5mm. Cracks filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings.</td></tr>
<tr><td>3</td><td>Moderate</td><td>0.15 – 0.30</td><td>Cracks 5-15mm, or number of cracks >3mm. The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced.</td></tr>
<tr><td>4</td><td>Severe</td><td>>0.3</td><td>Cracks 15-25mm. Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows.</td></tr>
<tr><td>5</td><td>Very Severe</td><td>>0.3</td><td>Cracks >25mm. This requires a major repair job involving partial or complete rebuilding.</td></tr>
</table>

</td></tr>
<tr><td><u>Foundations</u></td><td>▪ Type and arrangement<br>▪ As Historical Records above.</td></tr>
<tr><td><u>Discussion with owner / representative / occupier</u></td><td>▪ Record any relevant comments made, including:<br>– Local knowledge owner/resident/agent has with regards to their own or other structures in the vicinity.<br>– Issues or concerns raised (without prompting by surveyor) with regards to DMN and their structure.<br>– Report any difficulties encountered in accessing the structure including dates and times of denied access.<br>– Enquire whether owner/resident/agent has knowledge of information in relation to the structure, and where the information is held.</td></tr>
</table>

Railway Procurement Agency
Ghníomaireacht um Fháil Iarnród
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Parkgate Street, Dublin 8, Ireland
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