



**METRO NORTH
ORAL HEARING**

**Stage 2A Preliminary Building
Response Report
Rev3_Part1**

Dublin Metro North

**Stage 2A Preliminary Building
Response Assessment Report**

Revision 3

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Appendix E – Infrastructure Validation Data Sheets

Appendix F – Schedule of Infrastructure Included in the Stage 2A Assessment

Appendix G – Schedule of Mitigation & Protection Measures

Issue History

Issue	Date	Purpose
First Issue		First issue of Stage 2A report with some sections of the alignment omitted.
Revision 1	May 2008	<p>Stage 2A report revised to include the following sections of the alignment:</p> <ul style="list-style-type: none"> • Chainage 6+700m – 9+040m (Airport) • Chainage 12+170m – 13+400m (South of Ballymun to South of DCU) • Chainage 13+400m –14+600m (Griffith Avenue) • Chainage 14+600m – 15+880m (South of Griffith Avenue)
Revision 2	January 2009	<p>Stage 2A Revision 1 report revised to include the following sections of the alignment:</p> <ul style="list-style-type: none"> • Chainage 7+520m – 7+890m (Dublin Airport, update of Stage 1 Report according to the new asset information provided by DAA/IAA) • Chainage 16+660m – 17+530m (South of Mater Stop to North of O’Connell Bridge Stop, update of the Stage 1 Report to reflect the Railway Order Alignment drawings, 14 May 2008) • Chainage 18+680m – South end of the alignment (St Stephen’s Green Stop, Interconnector Eastbound Tunnel/DMN running tunnels crossing, and Loop arrangement) <p><i>Note: Ground movement assessment for revised sections based on master Alignment, BMN0000ML00911B01, 14 May 2008.</i></p>
Revision 3	February 2009	<p>Stage 2A Revision 2 report revised to include the following sections of the alignment:</p> <ul style="list-style-type: none"> • Cross passages Nos. 314, 315 and 316 relocated to coincide with positions shown on Railway Order Drawings Nos: <ul style="list-style-type: none"> - LMN000GA107002 Rev A - LMN000GA107003 Rev A - LMN000GA107004 Rev A • O’Connell Bridge Stop revised to reflect alternative design stop layout as shown on drawings BMN/0000/MU/8002 to BMN/0000/MU/8028.

Table A: Revision History.

Amendment Tracker – First Issue to Revision 1

Section	Amendment
General	Text revised and updated throughout report to include amendments relating to additional alignment sections.
Section 1	Table 1.1, Table 1.2, Table 1.3 and text updated to include amendments relating to additional alignment sections and updated assessment of airport infrastructure.
Table 4.2	Updated for inclusion of the revised areas stated above.
Section 4.2	Text deleted referring to exclusion of DAA property and infrastructure. Text added referring to pending information from DAA and IAA.
Section 5.8	Table 5.2 and Table 5.3 updated.
Table 7.1	Table updated to include Griffith Avenue.
Section 7.6.1	Text added referring to Chapelgate / St Joseph’s Avenue Wall and Tolka River (also applies to 7.6.2).
Section 7.7	Text added referring to Griffith Park footbridge.
Section 7.9.2	Text added referring to River Tolka.
Section 7.9.3	Further recommendations added: <ul style="list-style-type: none"> • Re-request for further information from WI. • No further study with regards to River Tolka
Section 7.10	Assessment of airport infrastructure updated based on further information received from DAA.
7.11.2	Text added: <ul style="list-style-type: none"> • Garden of Remembrance - Possible superficial damage which is unlikely to have structural significance. Recommend monitoring regime to be developed to ensure serviceability of pond. • Fusilier’s Arch (St Stephens Green Park) to be temporarily relocated to facilitate construction of St Stephens Green Stop. • Pavilions (St Stephens Green Park) - Possible superficial damage which is unlikely to have structural significance.
Section 7.12	Recommendation for DAA, IAA and WI asset information to be obtained.
Section 10.2.2	Text added in relation to monitoring of airport hardstanding areas.
Appendix A	Predicted Settlement drawings revised as indicted in drawing notes.
Appendix B	Building Response validation data sheets included for following sections: <ul style="list-style-type: none"> • Airport Section • DCU Stop to Griffith Avenue Stop • Griffith Avenue Stop to Drumcondra Stop • O’Connell Bridge Stop – St Stephens Green Stop • Griffith Avenue Stop • Drumcondra Stop <p>For building assessment validation datasheets adjacent to Stop boxes further clarity has been provided for calculating bending strain.</p>

Section	Amendment
Appendix C	<p>Building schedule revised to include additional areas stated above and Airport structures. Refer to Appendix C for schedule identifying inclusions and deletions.</p> <p>Drawings revised according to schedules.</p>
Appendix F	<p>Table F:1 amended to include section between DCU and Drumcondra Stop. Additions to table are:</p> <ul style="list-style-type: none"> • Albert College Road (lawn) • DCU Entrance • Griffith Ave. • Griffith Lawns • Hampstead Avenue • Bantry Road • Valentia Road • Home Farm Road <p>Table F:2 amended to include:</p> <ul style="list-style-type: none"> • Albert College Road (lawn) • Griffith Ave. <p>Table F:4 amended to include</p> <ul style="list-style-type: none"> • Chapelgate and St Joesph’s boundary wall <p>Table F:5 amended to include:</p> <ul style="list-style-type: none"> • St Patricks Footbridge <p>Table F:6 amended to include:</p> <ul style="list-style-type: none"> • Tolka River
Appendix G	<p>Infrastructure schedule revised to include additional areas stated above. Refer to Appendix G for schedule identifying inclusions and deletions.</p>

Amendment Tracker – Revision 1 to Revision 2

Section	Revision 1 to Revision 2 Amendment
General	Text revised and updated throughout report to include amendments relating to additional alignment sections. Refer to Table A – ‘Revision History’.
Section 1	<ul style="list-style-type: none"> • Section added explaining discrepancy in chainages presented within the body of the report compared to the ground movement drawings and Railway Order drawings. • Text added noting incorrect layout of O’Connell Bridge Stop and cross passages No.314 and No. 315 have been assessed. • Text added explaining that assessment excludes utilities located along alignment between DCU and Drumcondra Stops and along the alignment section presented in Table A. • Text revised to include the assessment of the Luas located along St Stephens Green West. • Text revised explaining the assessment of the new infrastructures identified within the Airport area from the new information provided by DAA and IAA.
Section 2.3	<ul style="list-style-type: none"> • Section added explaining discrepancy in chainages presented within the body of the report compared to the ground movement drawings and Railway Order drawings. • Text added noting incorrect layout of O’Connell Bridge Stop and cross passages No.314 and No. 315 have been assessed.
Section 4.2	<ul style="list-style-type: none"> • Text updated to include cross passages Nos 314 and 315. and utilities schedules for the alignment sections identified in Table A. –Revision History’ • Text deleted DAA / IAA issues and provision and review of outstanding Airport infrastructure and property information.
Section 6.2	Text added explaining that assessment excludes utilities located along alignment between DCU and Drumcondra Stops and along the alignment section presented in Table A.
Section 7.5	<ul style="list-style-type: none"> • Text amended for Luas infrastructure adjacent to O’Connell Bridge Stop due to incorrect Stop layout being modelled. • Text added to include the assessment of the Luas located along St Stephens Green West.
Section 7.10	Text revised explaining the assessment of the following Airport infrastructure: <ul style="list-style-type: none"> • Localiser 16 Shelter, Associated foundation and Equipment • Localiser 16 Antennae Array and Associated Foundations • Localiser 16 Near Field Monitor and Associated Foundations • Localiser 10 Near Field Monitor and Associated Foundations • Ducts providing power, communications and connectivity to the antenna array • Meteorological Equipment • Fuel Hydrants and Associated Pipework.
Appendix A	Drawing revision numbers updated.

Section	Revision 1 to Revision 2 Amendment
Appendix B	<p>Note added for discrepancy in chainages presented compared to the ground movement drawings and Railway Order drawings</p> <p>Validation data sheets included for following sections:</p> <ul style="list-style-type: none"> • Multi-storey car park and Hotel – Dublin Airport Building Response • South of Mater Stop to North O’Connell Bridge Stop (Ch. 16600 – 17530) • Parnell Square Stop and St Stephens Green Stop Building Response <p>Validation data sheets amended for inclusion of the new sections identified above in Table A:</p> <ul style="list-style-type: none"> • Mater Stop to Parnell Square Stop Building Response. • Parnell Square Stop to O’Connell Bridge Stop Building Response
Appendix C	<p>Building Damage Category Schedule and Amendment Trackers revised for inclusion of the alignment sections identified in Table A and Airport structures and property. Refer to Appendix C for schedule identifying inclusions and deletions.</p> <p>Settlement and Building Assessment Drawings chainages revised based on alignment drawing Ref: BMN0000ML00911B01, 14 May 2008. Other revisions include:</p> <ul style="list-style-type: none"> • BMN0000TU7067B03 – In abeyance removed at Parnell Square Stop • BMN0000TU7066B03 – In abeyance removed at St Stephens Green Stop,
Appendix D	Text added explaining that the table excludes utilities located along alignment between DCU and Drumcondra Stops and along the alignment section presented in Table A.
Appendix E	Datasheets revised to include new sections identified in Table A.
Appendix F	Infrastructure schedule revised for inclusion of the alignment sections identified in Table A. Refer to Appendix F for schedule identifying inclusions and deletions.
Appendix G	Schedule of Mitigation & Protection Measures revised for inclusion of the alignment sections identified in Table A. Refer to Appendix G for schedule identifying inclusions and deletions.

Amendment Tracker – Revision 2 to Revision 3

Note that changes from the Revision 2 to Revision 3 are denoted throughout the report by a vertical marker line in the left margin. The main changes to the report are summarised below.

Section	Revision 2 to Revision 3 Amendment
General	Text revised and updated throughout report to include amendments relating to additional alignment sections. Refer to Table A – ‘Revision History, Revision 3’.
Section 1	Text Amended: <ul style="list-style-type: none"> • Chainage Discrepancy: Text reworded for clarity • ‘Utilities Assessed in Stage 2A’: Locations of the alignment where utilities that have not been identified as part of this assessment include updated to include additional alignment sections included in Table A – ‘Revision History, Revision 2 and Revision 3’
Section 2.3	Text reworded for clarity
Section 2.4	Text amended to identify cross passage No. 316 exceeding design criteria of 250m. Recommendation made added to acknowledge that cross passage No. 316 slightly exceeds the 250m design separation (261m). Note added stating that final arrangement of O’Connell Bridge South box and spacing of cross passages would be subject to the detailed design by the DBFM contractor and acceptance of the final fire strategy.
Section 4.2	Text amended: <ul style="list-style-type: none"> • ‘Utilities Assessed in Stage 2A’: Locations of the alignment where utilities that have not been identified as part of this assessment include updated to include additional alignment sections included in Table A – ‘Revision History, Revision 2 and Revision 3’
Section 5.2	Text added: <ol style="list-style-type: none"> 5. The proposed new Multi-storey Car Park and Hotel complex at Dublin Airport has also been considered as part of the Stage 2A assessment at the requested of DAA. 6. 2nr piled buildings, which are non protected, non sensitive structures located along Westmoorland Street and are not subject to ground movements greater than 10mm have been subject to a Stage 2A assessment due to their locality in relation to the bored running tunnelling.
Section 5.8	Table 5.2 updated to include amended alignment sections included in Table A – ‘Revision History, Revision 3’
Section 6.2	Text amended: <ul style="list-style-type: none"> • ‘Utilities Assessed in Stage 2A’: Locations of the alignment where utilities that have not been identified as part of this assessment include updated to include additional alignment sections included in Table A – ‘Revision History, Revision 2 and Revision 3’

Section	Revision 2 to Revision 3 Amendment
Section 7.5.1	Text amended: First bullet point amended for new predicted ground movements attributed to alternative O'Connell Bridge Stop layouts (ground movement reduced from 50mm to 5mm)
Section 7.5.2	Text amended: a) amended for new predicted ground movements attributed to alternative O'Connell Bridge Stop layouts (ground movement reduced from 50mm to 5mm)
Section 7.11.2	Text delete due to revised O'Connell Bridge Stop layout: Sir John Gray, William South O'Brien and Daniel O'Connell monuments to be temporarily relocated to facilitate construction of O'Connell Bridge Stop.
Section 9.3	Text delete due to revised O'Connell Bridge Stop layout: 'The alignment of the ventilation adits north of O'Connell North access box is considered during any re-design exercise to reduce the impact of ground movements on the Luas. Alternatively measures such as a pipe arch/canopy are considered to protect the Luas tracks during construction of the ventilation adits.'
Appendix A	Predicted Settlement drawings revised to reflect Revision 3 amendments identified in Table A –'Revision History': <ul style="list-style-type: none"> • BMN0000TU7050B05 • BMN0000TU7051B05
Appendix B	Building Validation Assessment Datasheets update: <ul style="list-style-type: none"> • Parnell Stop to O'Connell Bridge Stop Building Response (Calculation 10) • O'Connell Bridge Stop Building Response (Calculation 11) <p>Additional text added to clarify assessment of Horizontal Strain for buildings adjacent to stop boxes.</p>
Appendix C	Building damage schedule updated and 'buildings identified for further assessment; revised to reflect Revision 3 amendments identified in Table A –'Revision History': <ul style="list-style-type: none"> • BMN0000TU7067B04 • BMN0000TU7068B04
Appendix D	Text amended: <ul style="list-style-type: none"> • 'Utilities Assessed in Stage 2A': Locations of the alignment where utilities that have not been identified as part of this assessment include updated to include additional alignment sections included in Table A – 'Revision History, Revision 2 and Revision 3'
Appendix E	Infrastructure validation datasheets updated to reflect Revision 3 amendments identified in Table A –'Revision History':
Appendix F	Infrastructure schedule updated to reflect Revision 3 amendments identified in Table A –'Revision History':
Appendix G	Schedule of Mitigation and Protection Measures updated to reflect Revision 3 amendments identified in Table A –'Revision History':

1. Executive Summary

Introduction

The purpose of this Stage 2A Assessment is to present the results of assessments undertaken to predict the response of overlying/adjacent property to ground movements generated by underground excavation of Dublin Metro North (DMN), and identify property that should be progressed to a Detailed Stage 3 Assessment to be undertaken by the Design Build Finance Maintain (DBFM) Contractor. In addition outline recommendations for mitigation and protection measures, and instrumentation and monitoring have also been provided.

1.1 Chainage Discrepancy

This revision (Revision 3), of the Stage 2A Preliminary Building Response Assessment Report presents an assessment of the predicted ground movement attributed to construction of Dublin Metro North. The assessment is based on the alignment plan which is included as part of the Railway Order Application, as specified under Section 37 of the Transport (Railway Infrastructure) Act, 2001 (Annex 1). The issue of this report coincides with the preparation of proofs of evidence for the Oral Hearing. However, the following discrepancy concerning alignment chainages has been identified:

The ground movement drawings presented in these reports adopt the chainages set out in the Railway Order Drawings. However, **chainage references within the text of this report are not compatible with the associated ground movement drawings.** This discrepancy has resulted from ongoing design development and alignment revisions, which were implemented by RPA during the initial and subsequent ground movement assessment.

Areas Excluded from Stage 2A Assessment

O'Connell Bridge and two Iarnród Éireann bridges located adjacent to the proposed DMN Drumcondra Stop are excluded as it is considered these structures should be the subject of detailed assessments now to gain approval in principles from Dublin City Council and Iarnród Éireann respectively.

Buildings & Structures Assessed in Stage 2A

The maximum tensile strains resulting from differential settlement and/or rotations of the foundations to buildings have been calculated based on the Stage 1 settlement predictions (see Appendix A) with a corresponding predicted damage category determined in accordance with Table 5-1. Buildings identified as falling within the 'Negligible', 'Very Slight' and 'Slight' categories will not be assessed further. Buildings classified as 'Moderate' or above categories will require further review as part of a detailed Stage 3 assessment to be undertaken by the DBFM Contractor.

In addition buildings deemed to be complex structures in terms of their response to ground movements, known to contain sensitive equipment, buildings which may incur particularly high repair costs, and prominent structures of significant historical or communal importance have also been recommended for further assessment. As a result 74nr buildings have been identified for a Detailed Stage 3 Assessment (see Table 1-1) to be undertaken by the DBFM Contractor. This is subject to the outcome of the contractors detailed design development which may identify additional buildings and structures requiring further assessment.

Building / Structure	Number of Buildings to Progress to Stage 3
Buildings classified as 'Moderate' or above	3
Piled Buildings	14
Prominent / Sensitive Structures & Buildings with a Building Characterisation Survey Condition Rating of 3 or Greater	57

Table 1-1 Summary of Existing Buildings to Progress to Stage 3

Utilities Assessed in Stage 2A

During the Stage 1 Preliminary Assessment it became apparent that critical information (utility size, depth and material) was for the vast majority of cases unavailable, preventing the assessment being progressed beyond Stage 1. This has been discussed with the RPA and at this time further assessment is not considered necessary to meet the requirement of the Railway Order Planning Application.

It is recommended that RPA and their utilities team consider collating the missing information to complete the Stage 1 utility schedules, and determine limiting ground movement criteria for all the utilities identified within the zone of settlement influence prior to appointment of the DBFM Contractor.

Locations of the alignment where utilities that have not been identified as part of this assessment include:

- utilities between chainages 13+260m – 15+745m (South of DCU Stop to south of Drumcondra Stop). These utilities have been omitted from this report due to an extended period of public consultation for this section of the alignment. Identification and assessment of utilities between DCU Stop and Drumcondra Stop will therefore need to be undertaken by the DBFM Contractor.

Due to continued design development the utilities schedule presented in Appendix D relates to previous ground movement predictions for the following sections of the alignment, and should be updated by the DBFM Contractor during the detail design.

- utilities between chainage 16+660m – 17+530m (South of Mater Stop to North of O’Connell Bridge Stop)
- utilities between chainage 17+630m – 17+770m (North of O’Connell Bridge Stop)
- utilities between chainage 17+770m – 18+060m (O’Connell Bridge Stop)
- utilities between chainage 18+680m – South end of the alignment (St Stephen’s Green Stop, Interconnector Eastbound Tunnel/DMN running tunnels crossing, and Loop arrangement)

Stage 2A Infrastructure Assessment

All infrastructure falling within the 2mm contour line of the Stage 1 settlement predictions have been considered by this Stage 2A Assessment. This review is based on known infrastructure details where available, or where unavailable, on experience, case histories, and the application of appropriate engineering principles.

Highways

Highways have been assessed firstly using 'Serviceability' criteria, followed by a risk based approach to consider particular features of the highway. Of the 93nr highways and associated walkways reviewed, 42nr are recommended to be taken forward to a Stage 3 Detailed Assessment (see Table 7-1). Particular consideration needs to be given to paved walkway areas, e.g. O'Connell Street where small settlements could create trip hazards and risk of injury.

Railway Track

The impact of ground movements on railways located at approximate chainage 15+800 (adjacent to Royal Canal in retained cutting) and chainage 16+000 (retained embankment supporting track and Drumcondra Station) have been assessed in terms of 'twist' and 'top' with rails predicted to deform within the Limiting Track Geometry Criteria specified by Iarnród Éireann (see Table 7-2).

Luas

The impact of the ground movements on the Luas track has been identified to occur at the following locations:

- North of the proposed O'Connell Bridge Stop vertical access box, perpendicular to the crossing of Abbey Street and Lower O'Connell Street (see Figure 7-4). The ground movements generated by construction of box will be assessed in the subsequent issue of this report (refer to Section 2.3)
- Adjacent to St Stephens Green Stop, along St Stephens Green West, ground movements generated by the construction of St Stephens Green stop are predicted to generate settlements of up to 7mm in the vicinity of the Luas St Stephen Green terminus. The predicted settlement along St Stephens Green West is not considered to affect the serviceability of the Luas infrastructure.

It is also noted that approximately 20m of the Luas line is located within St Stephen's Green Stop construction box. Therefore, the Luas line operation would be need to be suspended during box construction and the line removed and replace

Retaining Structures

Retaining structures have been assessed in accordance with recommendations set down by CIRIA Report 30 and are predicted to not be at risk of greater than superficial damage. However recognising their importance in terms of continual operation, and the scale of DMN construction in the close vicinity it is recommended a Detailed Stage 3 Assessment is undertaken by the DBFM Contractor based on structural/condition surveys, and detailed design and construction proposals of the below:

- i.) Retained embankment supporting Iarnród Éireann infrastructure (~Ch 15+780.)
- ii.) Retaining wall to Iarnród Éireann railway track adjacent to the Royal Canal (~Ch 16+000).
- iii.) Quay walls to River Liffey (~Ch 16+000)

Waterways

The Stage 2A Assessment concludes that the function of the identified waterways (Royal Canal, River Tolka and River Liffey) will not be compromised by ground movements generated by DMN construction. It is recommended that cross

passage No.310 currently located beneath the Royal Canal is relocated at the Detail Design Stage by the DBFM Contractor.

Airport Infrastructure

Based on information made available to date, the impact of ground movements generated by construction of DMN on the north and south aprons are not expected to compromise DAA operations, although there is a risk of cracking to the hard standing areas that may necessitate remedial measures to be undertaken during non-operational hours. Fuel hydrants and associated pipework within the apron have been assessed and are expected to accommodate the predicted movement.

In the vicinity of the DMN are Navigation systems. The systems have been assessed and appropriate protection / mitigation measures to preserve serviceability have been identified.

Monuments

Monuments identified by the Stage 2A Assessment have been identified as being subject to no more than superficial damage (see Appendix G). The Dublin Spire is predicted to settle less than 4mm and is not considered to be at risk of damage.

A total of 51nr. infrastructure items have been identified for further assessment by the appointed DBFM Contractor during Stage 3 (summarised in Table 1-2). This is subject to the outcome of the contractors detailed design development which may identify additional infrastructure items requiring further assessment.

Type of Infrastructure	Number of Items to Progress to Stage 3
Highways	42
Railways	4
Retaining Wall & Embankments	3
Waterways	0
Bridges	2
Monuments	0

Notes:

1. Iarnród Éireann railways to be assessed further by DBFM Contractor taking account of condition and results of sensitivity analysis

Table 1-2: Summary of Infrastructure to Progress to Stage 3

Code of Practice Risk Management

The relevant sections (with regards to ground movements) of the Code of Practice for Risk Management of Tunnel Works, prepared by The International Tunnelling Insurance Group (30 January 2006) have been reviewed. Table 8-1 of the main report summarises the current status, and actions/issues to be addressed to comply with the code.

Mitigation and Protection Measures

Buildings and infrastructure provisionally identified as requiring mitigation or protection along with recommended measures to be considered are scheduled by Appendix G.

Instrumentation and Monitoring

Currently the proposal for DMN is that all instrumentation and monitoring of the works should be carried out solely by the DBFM Contractor. Attention is drawn to the requirement for RPA to procure and implement instrumentation and monitoring to obtain baseline monitoring data 6 to 12 months before construction commences.

Key Recommendations

For detailed/particular recommendations Sections 5, 6, 7, 8, 9, and 10 of the main report should be referred to.

- Record drawings and limiting criteria for the following infrastructure items to be obtained wherever possible to assist bidders and ultimately the DBFM Contractor.
 - Highways (section 7.3)
 - Luas (section 7.5)
 - Embankments and retaining walls (section 7.6)
 - Dublin Spire (limiting criteria only)
 - Royal Canal (section 7.9.3)
 - Airport (section 7.10)
- All third party 'ground movement limiting criteria' to be incorporated in the third party requirements, or equivalent section of the Output Specification.
- The Stage 2A Infrastructure assessment assumes railway tracks and highway infrastructure are well maintained and in good condition. The Stage 2B Assessment should be based on condition survey information to validate this assumption.

2. Introduction

2.1 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.

Metro North will generally be separated from road traffic which will be achieved by running in tunnel in the city centre and on road medians or elevated sections in the less congested outer suburbs.

In July 2006, Jacobs was commissioned by the Railway Procurement Agency (RPA) to act as their Railway Engineering, Design and Safety Consultant for the Metro North project. The scope of the framework agreement included:

- Preparation of Reference Design.
- New works assessment.
- New rolling stock assessment.
- Assistance with preparation of Railway Order.
- Assistance with the administration of tenders from pre-qualification through to award.
- Engineering support during the Railway Order Public Inquiry.

2.2 Objectives

This report forms part of a suite of documents that set out the basis for predicting ground movements generated by underground excavation resulting from construction of Dublin Metro North (DMN) and the assessment of the subsequent impact of these ground movements on overlying/adjacent property, including buildings, utilities and infrastructure:

- Technical Note 12: Strategy for Assessing and Managing Building, Infrastructure and Utility Response to Ground Movements Generated by Underground Excavation.
- Design Input Statement for Predicting Ground Movements and the Response of Overlying Property to Underground Excavation.
- Stage 1 Preliminary Ground Movement Assessment Report, Revision 1, May 2008.

This document along with the above documents will form the basis for the appointed Design, Build, Finance and Maintain (DBFM) Contractor to conduct their own independent ground movement and property response assessment; Stage 2B Review of 2A Initial Response Assessment, and Stage 3 Detailed Response Assessment prior to commencement of DMN construction. Further details of the overall Building/Property Response Strategy is set out by Technical Note No.12.

The purpose of this Stage 2A Preliminary Building Damage Assessment Report is to present the results of analyses undertaken to predict the response of overlying/adjacent property including buildings, structures, utilities and infrastructure to the ground movement predictions detailed in the Stage 1 Preliminary Ground

Movement Assessment Report. This will include providing a schedule of all the buildings, utilities and infrastructure taken forward from the Stage 1 Preliminary Ground Movement Assessment accompanied by the results of this Stage 2A Assessment.

The scope of this Stage 2A Preliminary Building Response Assessment in accordance with Technical Note 12 includes:

- Calculation methods and assumptions applied.
- Reference to analysis input files and verification calculations.
- List of buildings/infrastructure included in the Stage 2A Assessment accompanied by corresponding:
 - Predicted settlement and ground slope.
 - Building / infrastructure risk of damage categorisation class where appropriate.
- Findings of utilities desk study.
- Confirmation that proposed Reference Design construction methods are appropriate.
- Recommendations for future work.
- Recommendations for instrumentation and monitoring, and settlement mitigation to be considered by the DBFM Contractor.

This Stage 2A Assessment has been carefully documented, including provision of Input Data Sheets in Appendices C & F to enable the bidders and ultimately the DBFM Contractor to understand the basis of the predictions, including input data and parameters that have been used. The provision of such information is considered vital to enable the DBFM Contractor to undertake the Stage 2B Assessment (verification and validation of the Stage 1 and 2A Assessments).

2.3 Chainage Discrepancy

For Dublin Metro North a continuous chainage system has been adopted. The chainage system allows unique points along the alignment to be referenced in relation to its topographical position. The chainage system for Dublin Metro North commences at the north of the alignment (the Depot) and increases southerly along the route.

During the design development process, the Master Alignment model for Dublin Metro North was subject to numerous revisions that necessitated amending chainages along the route.

In the development and subsequent revisions of this Stage 2A Building Response Assessment Report, different Master Alignment drawings have been referenced for the particular sections of alignment being assessed. Alignment models used in the development of the Dublin Metro North ground movement assessment are presented in Table 2-1.

Stage 2A Preliminary Building Response Report Issue Status	Master Alignment Drawings		
	Model Reference	Title	Date
First Issue, March 2008	BMN0000ML00911B01	Master Alignment 1:500	2 Oct 2007
Revision 1, May 2008	BMN0000ML00911B01	Master Alignment 1:500	22 Feb 2008
Revision 2, Jan 2009	BMN0000ML00911B01	Master Alignment 1:500	14 May 2008
Revision 3 Feb 2009	BMN0000ML00911B01	Master Alignment 1:500	14 May 2008

Table 2-1: Master Alignment Referenced for Dublin Metro North Ground Movement Assessment

Revision 1 of the Stage 1 Report incorporated a section of alignment between DCU Stop and Drumcondra Stop. This portion of the alignment was previously omitted due to an extended period of public consultation. As a consequence of establishing the final design alignment between DCU and Drumcondra, breaks in the chainages south of Drumcondra stop have occurred.

Revisions 2 and 3 of the Stage 2A Preliminary Building Response Assessment Report present a ground movement assessment based on the alignment plan which is included as part of the Railway Order Application, as specified under Section 37 of the Transport (Railway Infrastructure) Act, 2001 (Annex 1). The issue of this report coincides with the preparation of proofs of evidence for the Oral Hearing. However, it should be noted that the ground movement drawings presented in these reports adopt the chainages set out in the Railway Order Drawings. However, **chainage references within the text of this report are not compatible with the associated ground movement drawings.** This discrepancy has resulted from ongoing design development and alignment revisions, which were implemented by RPA during the initial and subsequent ground movement assessment at a number of locations along the alignment.

2.4 Cross passage Spacing

It is apparent from the Railway Order Drawings, (Ref LMN000GA107003 Rev A and LMN000GA107004 Rev A) and the station layouts for O’Connell Bridge Stop that cross passage No. 316 slightly exceeds the 250m design separation distance as specified in B0307000-010/TUN.007\001\1 (Cross Passage Space Proofing & Reference Design Report, May 2007). The separation of cross passage No. 316 from O’Connell Bridge Platform was found to be approximately 261m. However, it should be noted that final arrangement of O’Connell Bridge South box and spacing of cross passages would be subject to the detailed design by the DBFM contractor and acceptance of the final fire strategy.

3. References

The following is a list of references that have been used to develop this Stage 2A Report.

3.1 Metro North Papers

1. Technical Note 12: Strategy for Assessing and Managing Building, Infrastructure and Utility Response to Ground Movements Generated by Underground Excavation.
2. Design Input Statement for Predicting Ground Movements and the Response of Overlying Property to Underground Excavation .
3. Geo Design, Geological Assessment and Primary Lining Design – Mined Sections, O'Connell Street Stop, June 2007. Ref 262211/200707/Rev 01.
4. Stage 1 Preliminary Ground Movement Assessment Report, Revision 1, May 2008.

3.2 Other References

1. CIRIA Project Report 30 (March 1996), Prediction and effects of ground movements caused beneath urban areas.
2. Attewell; P.B. Yeates, J. Selby AR (1986) "Soil Movements Induced by Tunnelling and Their Effects on Pipelines and Structures", Blackie.
3. D M Miller, K H Bowers, JD Redgers, J M Reid and G T Clark The prediction and mitigation of tunnelling induced ground movement damage to structures. Unpublished Project Report Project PR/CE/203/96 E447A/BT. Highways Agency U.K.
4. Building Characterisation Surveys 2007 undertaken by:
 - CNP Property Surveys
 - Pat McGovern and Associates
 - Thorntons Chartered Surveyors

4. Methodology

4.1 Overview

The method of predicting ground movement and assessing the behaviour of buildings, utilities and infrastructure is a progressive process. For the Dublin Metro North project a 4 stage assessment process has been adopted. The various stages are summarised in Table 4-1 below:

Stage No.	Description
1	Stage 1 Preliminary ‘Greenfield’ Settlement Analysis – prediction of ground movements generated by underground excavation 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 Build Finance Maintain (DBFM) Contractor to review and update as appropriate the Stage 1 and 2A assessments.
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 DBFM Contractor.)

Note: Current Stage denoted by bold text

Table 4-1 Settlement Methodology and Stage Description

Prior to submission of the Railway Order, Stages 1 and 2A will be undertaken as part of the Reference Design for Metro North by Jacobs. The remaining stages of the process shall be undertaken by the DBFM Contractor.

Further details of the DMN strategy for assessing the response of buildings, utilities and infrastructure to ground movements generated by underground construction can be found in Technical Note No. 12, ‘*Strategy for Assessing and Managing Building, Infrastructure and Utility Response to Ground Movements Generated by Underground Excavation.*’

4.2 Areas Excluded from Stage 2A Assessment

The following structures are excluded from the Stage 2A Report:

- i.) O’Connell Bridge. The bridge is located above the proposed O’Connell Bridge Stop platform tunnels and next to the north and south vertical access boxes. Considering the complexity of the structure (two masonry structures), historical and operational significance to Dublin, and risk of ground movements generated by construction of O’Connell Bridge Stop it is considered that a Stage 2A assessment would be inappropriate since it would be unable to accurately quantify the risk and damage that could occur

to the structure. It is therefore recommended that specialist bridge engineers are employed to carry out a detailed inspection of the bridge, and make an assessment using this information to determine the appropriate level of the detailed Stage 3 Assessment to be undertaken. Consideration needs to be given to when and by whom this Stage 3 Assessment should be undertaken by, as it is likely Dublin City Council as part of their approval in principle to DMN O'Connell Bridge Stop would require RPA to demonstrate how the risk of damage to O'Connell Bridge would be managed.

- ii.) Two railway bridges (Iarnród Éireann) located adjacent to proposed Drumcondra Stop. The combination of Stop box and bored tunnel construction on these structures requires specialist bridge engineers to determine whether these structures are at risk of damage, and if so, what protection measures should be considered in order to gain an approval in principle from Iarnród Éireann.

Separate proposals for undertaking assessments of O'Connell Bridge and the Drumcondra Railway Bridges should be submitted to RPA for consideration.

As part of this Stage 2A assessment, schedules identifying utilities subjected to 10mm or greater ground movement have been prepared and are contained in Appendix D of this report. However, the schedules do not include:

- Utilities between DCU Stop and Drumcondra Stop. These utilities have been omitted from this report due to an extended period of public consultation for this section of the alignment. Identification and assessment of utilities between DCU Stop and Drumcondra Stop will therefore need to be undertaken by the DBFM Contractor.

Due to continued design development the utilities schedule presented in Appendix F relate to previous ground movement predictions for the following sections of the alignment.

- Chainage 16+660m – 17+530m (South of Mater Stop to North of O'Connell Bridge Stop)
- Chainage 17+630m – 17+770m (North of O'Connell Bridge Stop)
- Chainage 17+770m – 18+060m (O'Connell Bridge Stop)
- Chainage 18+680m – South end of the alignment (St Stephen's Green Stop, Interconnector Eastbound Tunnel/DMN running tunnels crossing, and Loop arrangement)

5. Stage 2A Buildings & Structures Assessment

5.1 Overview

Based on the predicted ground movement contour drawings presented in the Stage 1 Preliminary Ground Movement Assessment Report (and reproduced in Appendix A of this report), and the Stage 1 building assessment defined by Technical Note 12, predictions of the ground surface settlement and ground slope have been made at locations of existing buildings that may be adversely affected by ground movements generated by underground excavation. For each building identified as exceeding the Stage 1 criteria (see Section 5.2), a Stage 2A Initial Response Study has been undertaken that involves the assessment of the maximum tensile strain induced from predicted ground movements generated by underground excavation. This maximum tensile strain value has then been compared against the BRE251 Building Damage Classification System (see Table 5-1) to determine the predicted damage category for the building concerned.

Based on this Stage 2A Initial Response Assessment, buildings requiring a more detailed assessment of their response to ground movements have been identified. It is recommended these buildings are taken forward to the Stage 3 Detailed Structural Assessment to be undertaken by the DBFM Contractor.

5.2 Buildings Selected for Stage 2A Assessment

In accordance with CIRIA Project Report 30 and the DMN Technical Report 12, the following buildings and structures have been subjected to a Stage 2A Initial Response Assessment.

1. Building or structures where the predicted settlement from tunnelling is greater than 10mm or the predicted ground slope is greater than 1/500. Settlement and slope less than these values corresponds to a negligible damage classification (superficial damage unlikely).
2. Buildings within the zone of influence known to contain sensitive equipment, or buildings which will incur particularly high repair costs. These structures have been identified from site walkover, Ordnance Survey (O.S) mapping, topographical surveys and aerial mapping. Such structures include:
 - Churches
 - Hospitals
 - Theatres & Cinemas
 - Recording Studios
 - Prestigious retail property located in the vicinity of Grafton and O'Connell Street.
3. Prominent structures, buildings of significant historical or communal importance identified from Dublin City Council records of listed or protected buildings that fall within, or very close to the zone of influence.
4. Structures within the zone of influence identified during the Building Characterisation Surveys as having an existing damage classification of 3 (moderate damage) or greater in accordance with BRE Digest 251 (see Table 5-1).

5. The proposed new Multi-storey Car Park and Hotel complex at Dublin Airport has also been considered as part of the Stage 2A assessment at the requested of DAA.
6. 2nr piled buildings, which are non protected, non sensitive structures located along Westmoorland Street and are not subject to ground movements greater than 10mm (at surface level) have been subject to a Stage 2A assessment due to their locality in relation to the bored running tunnelling.

Applying the above criteria 435nr. buildings were identified for further assessment during Stage 1.

5.3 Building Characterisation Surveys

Building Characterisation Surveys have been undertaken on selected buildings to ascertain sufficient assessment details for this Stage 2A assessment to be undertaken. Information collected includes:

- Photographs and sketches of building.
- Building use (i.e. residential / office / retail / other).
- Age of building.
- Form of construction (i.e. infilled frame / open frame / masonry / other).
- Foundation type.
- Approx height (estimated from no. of storeys above ground).
- Whether the structure has a basement.
- Approx basement depth (i.e. no. of storeys below ground).
- Structural form of basement.
- General building condition (view on likely damage susceptibility / evidence of past foundation settlement / type and age of significant defects).
- Does building have an extension (including foundation type, connectivity to building).
- Building condition (BRE 251).
- Comments i.e. knowledge of any other sources of relevant information, local knowledge with regards to structures in vicinity, any indications of major reconstruction, any features of the building which may render the building sensitive to ground movement.

5.4 Risk of Damage Categories

The damage classifications set out in Table 5-1, are taken from BRE Digest 251 (1990) and Boscardin and Cording (1989), and have been used to assign the damage categories for this Stage 2A assessment based on the calculated tensile strains.

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.

Table 5-1 Building Damage Classification System

5.5 Predicted Movement of Existing Buildings

For this Stage 2A Assessment buildings have been modelled applying beam bending theory and assuming the foundations of the building adopt the ‘greenfield’ settlement profile of the ground. This approach, although conservative since it neglects any interaction between the stiffness of the buildings and the ground, is appropriate for this stage of building response assessment. The maximum tensile strains resulting from differential settlement and/or rotations of the foundations are calculated based on the ground surface settlement predictions presented in the Stage 1 Preliminary Ground Movement Assessment Report (reproduced in Appendix A of this report) and the corresponding predicted damage category determined in accordance with Table 5-1.

Buildings identified as falling within the ‘Negligible’, ‘Very Slight’ and ‘Slight’ categories will not be assessed further. Buildings classified as ‘Moderate’ or above categories will require further review as part of a detailed Stage 3 assessment to be undertaken by the DBFM Contractor.

In addition buildings that are deemed to be complex structures in terms of their response to ground movements generated by underground excavation, where the application of the Stage 2A building response assessment methodology is considered to be inappropriate are also recommended to be the subject of a Stage 3 Assessment.

5.6 Stage 2A Analytical Methodology

a) Mined and Bored Tunnels

For buildings overlying or adjacent to the running tunnels the Stage 2A Building Response Assessment has been carried out using Jacobs in-house program DeltaB. For each building identified the predicted damage category has been determined using the best estimate ground movement parameters set down in

‘Design Input Statement for Predicting Ground Movements and Response of Overlying Property to Underground Excavation’.

Zones of hogging or sagging have been identified along each building side, and for each hogging or sagging section, the horizontal strain, bending strain and shear strain has been calculated. The total bending strain and the total shear strain is then determined. The greater of these two values is the limiting tensile strain, which is used to predict the damage category for the building in accordance with Table 5-1.

b) Cut and Cover Structures

For buildings and structures adjacent to stop boxes the Stage 2A Building Response Assessment has been carried out taking account of the particular settlement profile predicted for each Stop (a function of construction sequencing, wall stiffness, propping arrangement and ground conditions) and geometrical and orientation characteristics of the building being considered. Manual calculations have been undertaken to determine the limiting tensile strain and the corresponding predicted damage category for each building considered.

c) Piled Buildings

Assessment of buildings founded on piles has been conducted using the methodology proposed by Kaalberg et al (1999) and guidance provided by Professor John Burland. The assessment approach is as follows:

1. Any building with the pile tips located in zones A and B as defined by Figure 5-1 shall automatically progress to Stage 3 for detailed assessment by the DBFM Contractor. This approach has also been adopted for assessing piled buildings adjacent to deep excavations whereby zone B originates from the base of the excavation wall.

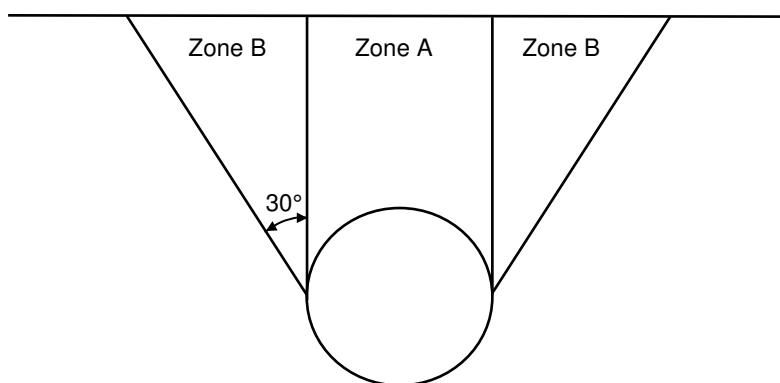


Figure 5-1 Zone of pile movement around a tunnel (after Kaalberg et al., 1999)

2. For piled buildings lying outside zones A and B the corresponding damage category will be calculated assuming that the building is not on piles. If the potential damage is assessed to be greater than Category 2 then these buildings will be passed over to Stage 3 for detailed assessment.
3. Piled buildings and structures where pile toes are below the tunnel invert, or the toe of cut and cover retaining wall structures are not considered to be at risk of damage greater than Category 2.

Regardless of the predicted damage category of the piled building the influence of lateral earth movements and down-drag on the structural capacity of the piles needs to be considered for areas where excavations, bored tunnelling or ground treatment is to be conducted in the close vicinity of existing piles. The lateral and vertical movements, axial stresses and bending moments can be assessed using numerical analyses software such as PLAXIS or FLAC.

5.7 Analysis Input Files and Verification Calculations

Data sheets recording the input parameters used for the building response assessment and relevant references have been produced and are presented in Appendix B. The data sheets record the parameters used to enable the building response assessments to be verified. In addition this information will be essential to enable the DBFM Contractor to undertake his Stage 2B Assessment (Review and update Stage 1 and 2A assessments). The data sheets provide:

- A description of the analysis undertaken
- A brief description of the methodology applied
- Drawing references used
- Assumptions
- Input parameters
- File name

Input parameters for the building response assessment have been obtained from Characterisation Surveys, site walkover, topographical survey background mapping, and O.S. background maps where the topographical survey does not cover the full extent of the predicted zone of influence. A further walkover of the alignment has also been undertaken to validate input parameters.

Analysis results have been validated in accordance with the 'Design Input Statement for Predicting Ground Movements and the Response of Overlying Property to Underground Excavation' including independent validation of the results using alternative methods of calculation.

5.8 Results

For each building identified by the Stage 1 Assessment to be taken forward to Stage 2A, damage categories have been predicted and assigned applying the methodology described above. The results of the Stage 2A assessment are presented on the schedules contained in Appendix C. A summary of the predicted damage category for all the buildings assessed to date is presented in Table 5-2.

Category of damage	Normal degree of severity	Number of Buildings
0	Negligible	313
1	Very Slight	82
2	Slight	21
3	Moderate	2
4	Severe	1
5	Very Severe	0

This table excludes the following buildings:

- Mater Misericordiae University Hospital and Rotunda Hospital (buildings A - Main Hospital and B – Reception area) which are located outside the predicted zone of influence and therefore have not been subjected to a building response assessment.
- Nr. 14 buildings which have been identified to be on piled foundation and automatically progressed to Stage 3 for detailed assessment (Refer to Section 5.6.)

Table 5-2 Breakdown of Buildings by Predicted Damage Category

Buildings categorised as ‘Moderate’ or above will require further review as part of the detailed Stage 3 assessment by the DBFM Contractor. In addition, buildings identified within the zone of influence that are considered structurally complex (see paragraph 5.5), known to contain sensitive equipment, buildings which may incur particularly high repair costs, prominent structures and buildings of significant historical or communal importance will also be carried forward to Stage 3.

Buildings recommended to be carried forward to the detailed Stage 3 assessment are presented in the schedule and drawings contained in Appendix C. In total 74nr buildings have been identified for further assessment. A summary of the number of buildings to be carried forward to Stage 3 is presented in Table 5-3 below.

Building / Structure	Number of Buildings to Progress to Stage 3
Buildings classified as ‘Moderate’ or above	3
Piled Buildings	14
Prominent / Sensitive Structures & Buildings with a Building Characterisation Survey Condition Rating of 3 or Greater	57

Table 5-3 Summary of Buildings to Progress to Stage 3

5.9 Recommendations

Based on this Stage 2A Initial Building Response Assessment it is recommended:

- The DBFM Contractor undertakes a Stage 2B Assessment to verify and validate the findings of this Stage 2A study, including taking account of any changes to the Reference Design on which this assessment has been based. Including but not limited to changes to the alignment, construction methodology and sequencing, improved understanding of the ground conditions as a result of the Main Ground Investigation and the DBFM’s Contractor’s own assessment of the ground conditions.
- Subject to the verification and validation of this Stage 2A assessment by the DBFM Contractor, all the buildings identified by Table 5-3 are to be the

subject of a Stage 3 Detailed Assessment undertaken by the DBFM Contractor.

- The DBFM Contractor shall ensure that protection measures are implemented as required to ensure that no building has a damage category of 2 or above in accordance with Table 5-1.
- Irrespective of the predicted damage category for buildings founded on piles, all piles subjected to lateral earth movements and down-drag will require a detailed check (to be undertaken by the DBFM Contractor) to ensure the structural capacity of the pile(s) is not exceeded.

6. Stage 2A Utilities Assessment

6.1 Overview

There are numerous underground utilities located along the proposed Dublin Metro North alignment. These include gas mains, water mains, sewers, drains, power cables and telecommunication ducts. These utilities are constructed of various materials (cast iron, steel, polyethylene, masonry etc), they will be in different states of condition/repair, and carry/transmit gas, water, electricity, telephone etc, some of which are considered safety critical items in the event of damage i.e. gas. As a result there will be a range of different acceptable tolerances to total settlement, differential settlements and strains for individual utilities.

6.2 Utilities Identified for Further Assessment

The locations and details of existing utilities along the route of DMN have been obtained by the RPA Utility Team from various utility undertakers. Based on this information Jacobs have identified 2,925nr. utilities within the zone of settlement influence based on the ground movement contour drawings presented in the Stage 1 Preliminary Ground Movement Assessment Report (and reproduced in Appendix A of this report). However it should be noted that this assessment excludes:

However, the schedules do not include:

- Chainage 13+260m – 15+745m (South of DCU Stop to south of Drumcondra Stop). These utilities have been omitted from this report due to an extended period of public consultation for this section of the alignment. Identification and assessment of utilities between DCU Stop and Drumcondra Stop will therefore need to be undertaken by the DBFM Contractor.

Due to continued design development the utilities schedule presented in Appendix F relate to previous ground movement predictions for the following sections of the alignment.

- Chainage 16+660m – 17+530m (South of Mater Stop to North of O'Connell Bridge Stop)
- Chainage 17+630m – 17+770m (North of O'Connell Bridge Stop)
- Chainage 17+770m – 18+060m (O'Connell Bridge Stop)
- Chainage 18+680m – South end of the alignment (St Stephen's Green Stop, Interconnector Eastbound Tunnel/DMN running tunnels crossing, and Loop arrangement)

During the Stage 1 Preliminary Ground Movement Assessment Report it became evident from the information supplied by the RPA's utility team that whilst it was possible to identify the type and location of utility from drawings supplied, information in terms of utility size, depth and material was for the vast majority of utilities unavailable. This issue was discussed between Jacobs (P Brown and P O'Driscoll) and RPA (G Featherstone) on 9th January 2008 where it was agreed that a Stage 2A assessment of the response of utilities was not required pre-Railway Order. On this understanding further assessment of utilities beyond Stage 1 has not been undertaken by Jacobs. This is a change in approach to that set down by Section 6 of Technical Note 12, Strategy for Assessing and Managing Building, Infrastructure and Utility Response to Ground Movements Generated by Underground Excavation, (written assuming sufficient information would be available

to complete Stage 1 and 2A assessments) where now the DBFM Contractor will be required to complete the Stage 1 and 2A utility response assessments to determine which utilities should be the subject of a Detailed Stage 3 Assessment.

The Stage 1 Assessment identified 463nr utilities (excluding the sections of alignment noted above) as being subject to 10mm or greater ground movement. The significance of 10mm being the:

- Threshold for when brittle pipelines i.e. cast iron may be expected to incur damage in accordance with the recommendations of Attewell (1986) 'Soil Movements Induced by Tunnelling and Their Effects on Pipelines and Structures'
- Masonry structures i.e. brick lined sewers where the predicted settlement is less than 10mm or the predicted slope less than 1/500, and therefore anticipated to be at risk of negligible damage only (superficial damage unlikely) in accordance with guidance provided by CIRIA Project Report 30.

A schedule of utilities subjected to 10mm or greater ground movement has been reproduced in Appendix D of this report.

6.3 Recommendations

Considering the above it is recommended that:

- DBFM Contractor to update the Stage 1 utility schedules with missing information (utility size, depth and material) and for the section of the route between DCU and Drumcondra Stops that has not been assessed by Jacobs in terms of utilities falling within the settlement zone of influence.
- RPA utilities team to schedule (date, person specifying requirement, and details of particular requirement) any particular requirements communicated to them by utility owners with regards to ground movements. This information can then be passed to the bidders and eventual DBFM Contractor.
- RPA and their utilities team to consider the benefits of collecting the missing information (utility size, depth and material, omitted sections of the alignment) required to complete the Stage 1 utility schedules, and determine the limiting ground movement criteria for all the utilities identified within the zone of settlement influence prior to appointment of the DBFM Contractor. This would enable the DBFM Contractor to focus on utilities/areas with particular issues rather than enter into protracted negotiations with utility owners to collect base information and determine acceptable ground movement limits.
- Subject to the verification and validation of the Stage 1 assessment by the DBFM Contractor, all the utilities identified by the Stage 2B Assessment (undertaken by the DBFM Contractor) as being at risk of unacceptable damage are to be the subject of a Stage 3 Detailed Assessment undertaken by the DBFM Contractor.
- Utilities identified as being at risk of unacceptable damage to be protected or diverted, or construction methodology modified to reduce risk to acceptable levels.

7. Stage 2A Infrastructure Assessment

7.1 Overview

The identification and assessment of infrastructure which may be adversely affected by construction of the proposed DMN scheme is dependent on individual/particular performance and operational requirements, form of construction and asset condition. The infrastructure encountered within the DMN settlement zone of influence is diverse. For assessment purposes, infrastructure has been grouped into the following categories:

- Highways
- Railways
- Luas
- Embankments, Retaining Walls and Walls.
- Bridges
- Electrical Sub-Stations
- Waterways (Rivers and Canals)
- Airport Infrastructure
- Monuments

Infrastructure has been identified firstly from topographical surveys and OS mapping, and then a walk over of the route has been undertaken to ensure all items of infrastructure have been identified.

All infrastructure identified will have particular criteria in terms of acceptable ground movements. For this Stage 2A assessment all the infrastructure falling within the 2mm settlement contour line (see Stage 1 Settlement Contour drawings contained in Appendix A) has been reviewed, and where appropriate assessed in further detail to determine likely response to ground movements generated by underground excavation of DMN.

An assessment of the impact of ground movements on identified infrastructure using the Stage 1 settlement contour drawings has been undertaken based on known infrastructure details where available. Where infrastructure details are lacking or unavailable typical structural arrangements and assessment criteria have been applied based on experience, case histories, and application of appropriate engineering principles.

Where there is insufficient asset information available to make an informed assessment of the impact of ground movements on the item of infrastructure in question, or where the infrastructure under consideration is deemed to be intrinsically important to the operation of Dublin, it is recommended that these items of infrastructure should automatically progress to Stage 3 for detailed assessment by the DBFM Contractor.

For each element of infrastructure reviewed, recommendations particular to that element have been made. In addition there are overarching recommendations applicable to all the infrastructure elements considered. These have been identified at the end of this Section 7.

7.2 Analysis Input Files and Verification Calculations

Data sheets recording the input parameters used for the infrastructure response assessment and relevant references have been produced and are presented in Appendix E. The data sheets record the parameters used to enable the infrastructure response assessments to be verified. In addition this information will be essential to enable the DBFM Contractor to undertake his Stage 2B Assessment (Review and update Stage 1 and 2A assessments). The data sheets provide:

- A description of the analysis undertaken
- A brief description of the methodology applied
- Drawing references used
- Assumptions
- Input parameters
- File name

Input parameters for the infrastructure response assessment have been obtained from site inspections, record drawings, third party particular requirements, OS mapping.

Analysis results have been validated in accordance with the Design Input Statement for Predicting Ground Movements and the Response of Overlying Property to Underground Excavation including independent validation of the results using alternative methods of calculation.

7.3 Highways

7.3.1 Assessment Methodology

A total of 93nr highway structures that fall within the 2mm contour line of the Stage 1 Settlement Contour drawings have been identified along the route of DMN for consideration by this Stage 2A Assessment and are scheduled in Appendix F, Table F:1. Types of road identified include:

- 'N' classified roads
- 'R' classified roads
- Urban roads
- Residential roads
- Roads within the boundaries of Dublin Airport

The effects of DMN induced settlements on highways have been assessed based on the assumption that:

- Deformation of highways adopt a 'greenfield' settlement profile i.e. no account is taken of the inherent stiffness of the highway pavement/structure itself. It has been necessary to adopt this approach due to details of pavement construction being unavailable. (It has only been possible to date to gain an appreciation of pavement construction from a route walkover).
- The highways and walkways considered by the Stage 2A Assessment are well maintained and in good condition in terms of serviceability and drainage.

Based on the 'greenfield' settlement predictions (see Stage 1 Settlement Contour drawings contained in Appendix A) the assessment of highways has been undertaken in two stages:

1. Assessed using 'Serviceability' criteria. Highway serviceability failure is measured in terms of poor performance of the asset due to excessive change in gradient, cross fall and / or road drainage inefficiency. These performance criteria are more critical and onerous in determining the performance of a highway than risk of structural damage.
2. For those highways identified by the first stage as exceeding the serviceability criteria, or highways deemed to be particularly sensitive to ground movements ('R' and 'N' graded roads) a risk based approach has then been adopted to consider particular features of the highway to assess whether further assessment is required.

1. Serviceability Assessment

The serviceability assessment of highway structures is based on the methodology proposed by Jordan (1984) which relates the highway ride quality to the induced settlement. This method assesses the vertical radius of curvature over the area of pavement affected. Where the measure of vertical radius of curvature is used as a benchmark to measure performance in terms of excessive change in gradient, cross fall and / or road drainage inefficiency; consideration is then given to vertical acceleration experienced in road vehicles for particular traffic speeds. These accelerations have been correlated with acceptable ride quality criteria, where:

- Accelerations of less than 0.6 m/s^2 are acceptable.
- Accelerations of greater than 1.5 m/s^2 are uncomfortable.

The accelerations that vehicles experience when travelling across the settlement trough is dependant on their traffic speed. Therefore a combination of travel speed and vertical acceleration are used to determine the category of comfort experienced by the user.

Based on the above criteria any road calculated to have an acceleration of 0.6 m/s^2 or greater has been identified for further consideration by the risk based approach described below.

The road speed limit for urban areas in the Republic of Ireland is 50km/h, for highways of category 'R' it is 80km/h, and for highways of category 'N' it is 100 km/h. All the roads considered by the Stage 2A assessment fall within urban areas therefore a maximum speed limit of 80 km/h (50mph) has conservatively been assumed.

There is no known documented guidance with regards to when the magnitude of settlement becomes unacceptable to highway performance, however based on discussions with experienced Jacobs Highway Engineers assessment criteria for permissible settlement of highways has been established. Values of 5mm settlement are considered to be tolerable for carriageways; however this magnitude of settlement may result in uneven surfaces on footpaths causing potential trip hazards to pedestrians, particularly paved areas such as O'Connell Street. In such cases regular monitoring and inspection of footpaths/footways would be required and remedial works instigated in good time to prevent injury to pedestrians from trips and falls.

2. Risk Assessment

In addition to the serviceability assessment described above a risk based approach has also been adopted to further review the roads identified by the serviceability assessment as falling below the acceptable serviceability criteria. In addition all 'R' and 'N' classified roads identified have been reviewed using this risk based approach. Roads with bus routes have also been selected for assessment. The risk

assessment has been undertaken in conjunction with an experienced highways engineer with consideration being given to particular features of the highway:

- Surfacing material and condition (determined during site walkover).
- Condition (determined during site walkover).
- Traffic levels/usage.

The Risk Assessment has been completed considering:

- Likelihood of 'ponding' occurring.
- Requirement for temporary repair.
- Requirement for permanent repair.

An assessment of the temporary and permanent situations has also been undertaken for walkways. The Risk Assessment considers the amount of settlement for each highway and assumes that values of settlement of less than 5mm are within the serviceability limits of the highways, whereas for walkways it could create a trip hazard.

Risks have been graded between low and very high, where any road or walkway given a risk rating of medium or greater is recommended to be taken forward to the Stage 3 Detailed Assessment.

7.3.2 Results of Stage 2A Assessment

The results of the Serviceability and Risk Assessments are presented in Appendix F, Tables F.1 and F.2 respectively.

Based on the assessment methodology described above, Table 7-1 summarises the roads and walkways identified by the schedules contained in Appendix F that are recommended to be taken forward to the Stage 3 Detailed Assessment to be undertaken by the DBFM Contractor. In total there are 42nr roads to be taken forward.

Item No.	Road Name	Description
4	Naul Road (R108)	Footpath
7	Internal service airport Road	Footpath
8	Swords Road	Footpath
9	Swords Road	Footpath
10	Airport Road	Footpath
13	Ballymun Road (R108)	Footpath
19	Griffith Avenue	Highway
24	St Joseph's Avenue	Footpath
31	Whitworth Road	Footpath
40	North Circular Road (R101)	Highway
41	Leo Street	Highway
44	Leo Ave	Footpath
45	Eccles Street	Highway
46	St Joseph's Parade	Highway
47	St Joseph's Place	Footpath
48	St Joseph's Place	Footpath
49	Blessington Court	Footpath
50	Blessington Street	Highway
51	Dorset Street Lower (N1)	Highway
52	Dorset Street Upper (N1)	Highway
53	Frederick Street North	Highway
54	Hardwicke Street	Highway
55	Denmark Street / Gardiner Row	Highway
56	Frederick Lane North	Footpath
57	Parnell Square North	Highway
58	Parnell Square East	Highway
59	Cavendish Row	Footpath
60	Parnell Street	Highway
61	O'Connell Street Upper	Highway
62	Cathal Brugha	Highway
63	Cathedral Street	Highway
66	O'Connell Street Lower	Highway
73	Bachelors Walk	Footpath
74	Burch Quay	Highway
75	Aston Quay	Footpath
76	Westmorland Street	Highway
77	D'Olier Street	Highway
80	College Green	Highway
89	Grafton Street	Footpath
90	King Street South	Highway
91	St Stephens Green North	Highway
92	St Stephens Green West	Highway

Table 7-1 Summary of Highways and Walkways Recommended for a Stage 3 Detailed Assessment

Based on experience of highway maintenance, settlements of up to 50mm are considered permissible for carriageways and could be managed for temporary situations providing the ground slope is not greater than 1:500. However remedial works would be expected to be required on the cessation of significant ground movement to reinstate and make good road surfaces.

7.3.3 Particular Recommendations

Considering the above, particular recommendations for highways and walkways are made as follows:

- Condition surveys of the roads should be undertaken by the DBFM Contractor as part of the Stage 2B Assessment to verify the validity of the assumption made by this Stage 2A Assessment that the roads and walkways identified by the Stage 1 and 2A Assessment are maintained in good condition in terms of serviceability and drainage.
- Following completion of the Stage 3 Detailed Assessment, roads and walkways that are still considered to be at risk of unacceptable damage during the temporary stage (i.e. during construction) will require protection or mitigation measures to be designed and installed by the DBFM Contractor. In addition where the condition of roads and walkways suffers deterioration as a result of DMN Works, but this deterioration is acceptable in the temporary state, they will require permanent reinstatement to the condition they were in before deterioration caused by DMN works once significant ground movements have ceased.
- It is recommended that the assessment methodology and criteria described above is reviewed by the appropriate authority for the roads identified i.e. National Roads Authority (NRA), Dublin City Council etc.
- The DBFM Contractor should undertake an assessment of the road drainage systems in accordance with the recommendations made by Section 6.3.
- Routine inspection and maintenance undertaken of paved areas as required by DBFM Contractor to prevent trip hazards from occurring that could cause injury to pedestrians.

7.4 Railways

7.4.1 Assessment Methodology

Ground movements induced by tunnelling and box excavation may adversely affect rail infrastructure and cause localised track performance criteria to be exceeded. The DMN alignment passes underneath Iarnród Éireann (Irish Rail) operational infrastructure south of DMN Drumcondra Stop at two locations:

1. Approximate Chainage 15+800 - Almost immediately south of DMN Drumcondra Stop the twin bored running tunnels pass beneath the retained embankment along which twin railway tracks run (see Figure 7-1 and Figure 7-2). The railway would also be expected to be affected by ground movements generated by excavation of the adjacent DMN Drumcondra Stop box.



Figure 7-1 Retained embankment (looking at south side) carrying twin railway tracks



Figure 7-2 Twin railways tracks running along top of retained embankment

2. Approximate Chainage 16+000 – Twin bored running tunnels pass beneath the twin track railway line (see Figure 7-3). The railway would also be affected by construction of cross passage No.310 that includes a sump.



Figure 7-3 Twin Track Railway Line in Retained Cutting

This Stage 2A Assessment assumes that the existing track geometry of the above railway lines is in good condition and well maintained.

Based on the 'greenfield' settlement predictions (see Stage 1 Settlement Contour drawings contained in Appendix A) a Stage 2A Assessment of the impact of these 'greenfield' settlement values on the affected rails has been undertaken to assess the potential deformation at track level. Predicted rail deformations have then been compared with limiting track geometry criteria provided by Iarnród Éireann and summarised by Table 7-2.

Third Party Specification : Limiting Track Geometry Criteria	
LIMITING CRITERIA FOR SHORT TWIST (2.7 M Baseline)	
Twist <1 in 540	Green
Twist between 1 in 540 and 1 in 271	Amber
Twist >1 in 270	Red
LIMITING CRITERIA FOR LONG TWIST (10.8 M Baseline)	
Warp <1 in 1120	Green
Warp between 1 in 560 and 1 in 1120	Amber
Warp >1 in 560	Red
LIMITING CRITERIA FOR TOP (5.4 M Baseline)	
Difference in Top <5mm over 5400 m	Green
Difference in Top between 7.5mm and 10mm over 5400mm	Amber
Difference in Top > 10mm in 5400mm	Red

Table 7-2: Limiting Track Geometry Criteria provided by Iarnród Éireann.

Table 7-2 provides limiting criteria in terms of rail deformation with corresponding trigger limits defined as follows:

- Short Twist – Difference in cant over a 2.7m baseline
- Long Twist – Difference in cant over a 5.4m baseline
- Top – Difference in rail level along the top of rail between the mid point and end points over a 5.4m baseline
- Green: Within acceptable limits.
- Amber: Serviceability limit - Notification to Iarnród Éireann; assessment of continuous monitoring, maintenance/action to be taken to remediate.
- Red: Operational limit – Suspension of works & continuous monitoring until further notified by Iarnród Éireann. Emergency maintenance required to remediate.

Full descriptions of the Green, Amber and Red action levels can be found in Appendix F, 'Third Party works: Specification for Movement Monitoring of Railway Track', Section A.6.

In addition to considering the impact of the total 'greenfield' settlements shown by the Stage 1 Settlement Contour drawings, consideration has been given to the transient development of settlements, including the impacts of ground movements ahead of the tunnel face. The assessment assumes the excavation of DMN Drumcondra Stop is completed first before TBM breakout from the south end of Drumcondra Stop box, and that the total predicted ground movements due to Stop excavation have occurred (worst case scenario). The transverse settlement trough profile (perpendicular to the direction of tunnel drive) provides the worst case in terms of slope and has therefore been used to establish the critical case in terms of the criteria set down by Table 7-2.

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