



**METRO NORTH
ORAL HEARING**

PROOF OF EVIDENCE

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Monitoring

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Metro North Oral Hearing

Proof of Evidence

Movement Monitoring and the Role of RPA

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Movement Monitoring and the Role of RPA

In response to a request made by the Inspector's technical adviser this evidence sets out how the underground works will be monitored to ensure they are executed correctly and safely.

1 Introduction

The Metro North project involves tunnelling and a number of deep excavations in a dense urban environment in variable ground conditions. The response of the ground to this construction has the potential to influence the behaviour of the overlying and surrounding buildings and infrastructure.

The tunnelling and deep excavations are geotechnical processes that are controlled by the contract specifications and the Contractor. It is the assessment of, and response to the ground conditions encountered that affects the degree of ground movement generated. This control depends on the behaviour and response of the ground and groundwater which will change as the geological ground conditions change. The following sets out the measures that will be instigated by RPA to monitor and control tunnelling and deep excavations to ensure that the works are executed correctly and safely.

2 Instrumentation and Monitoring

2.1 Overview

As stated previously by Professor John Burland all buildings and infrastructure assessed to be potentially at risk from ground movements will be monitored. The degree of monitoring will depend on the amount of settlement predicted and on the type of building or infrastructure. The monitoring will vary from periodic levelling of settlement points on a building to more extensive monitoring of horizontal movements as well as vertical movements.

The monitoring will be used to check that the behaviour of each building or infrastructure is within acceptable limits as determined by the detailed settlement and ground movement analysis. Any significant departure from the predicted response identified as below ground excavation progresses will be fully analysed in order that appropriate contingency measures can be implemented if deemed necessary.

2.2 Baseline Movement Monitoring

The response of the ground, buildings, and infrastructure will be monitored for movement. This monitoring will be carried out over a time-scale commencing prior to the tunnelling and excavation works to a point when the trends of the excavation induced ground movements and the behaviour of affected buildings and infrastructure can no longer be distinguished from movements induced by seasonal or natural causes.

RPA will undertake baseline movement monitoring approximately 6 to 12 months prior to work commencing in areas where the Metro North works could potentially have an impact to enable the effects of the works to be distinguished from seasonal and natural causes. The buildings identified for baseline monitoring have been selected based on ground movement predictions made by RPA.

A baseline monitoring regime in the vicinity of Mater and Parnell Square Stops has been designed by RPA and reviewed and approved by Professor Burland. This package of work is currently out to tender for installation of the instrumentation arrays and subsequent ongoing monitoring. These two areas have been developed in advance as they are the subject of enabling works. The slides provided are examples of the baseline monitoring designs developed. They comprise an extensive array of levelling points and prisms placed external to the buildings to enable vertical and three dimensional moments to be recorded. In addition prisms are used to enable the building or structure to be surveyed remotely where access is difficult. Also included are internal levelling points for the following selected structures:

- The bunker structure that house the linear accelerators in the Mater Private Hospital,
- the basement to the Abbey Presbyterian Church, and
- the ground floor of the Ambassador Theatre.

Further baseline monitoring schemes are currently being designed by RPA for other below grade stop sites where property is predicted to fall within the ground movement zone of influence, as well as some greenfield monitoring points being installed to enable the performance of the tunnel boring machine to be validated before it passes beneath densely built up areas.

All the baseline movement monitoring data will be reviewed and assessed by RPA's tunnelling and geotechnical engineers and Professor Burland. It will also be passed to the Contractor in good time before he commences construction so that it can be taken account of in the design of his monitoring system.

As such RPA will ensure that all necessary baseline monitoring will be complete to allow a timely start of the excavation works required to commence early after financial close. The remaining baseline monitoring to be undertaken over and adjacent to the bored and mined running tunnels will be designed and implemented by the Contractor since there will be sufficient time available after financial close to design and undertake baseline monitoring whilst preparations are made to launch the tunnel boring machines (TBM's), and for the TBM's to progress along the alignment.

It is also of note that baseline groundwater monitoring of approximately 90 boreholes has and continues to be undertaken.

2.3 Movement Monitoring During the Works

For Metro North there are two basic purposes of field instrumentation and monitoring:

1. The Contractor will need to control the various geotechnical processes involved in the tunnelling and excavation works. It is right and proper that he should be responsible for installing, reading and interpreting instrumentation and monitoring which are required solely for these purposes and that may include.
 - Optical/electronic surveying methods
 - Portable displacement gauges

- . Single point monuments
 - . Vertical pipe settlement gauges
 - . Remote settlement gauges
 - . Heave gauges
 - . Inclinometers and electrolevels
 - . Borehole extensometers
 - . Soil strain gauges
 - . Tunnel convergence
 - . Piezometers
2. RPA need to be assured that the excavations and tunnels, ground, groundwater levels, groundborne vibration levels and associated building and infrastructure movements are within the specified tolerance and be given the earliest possible warning of movements that are progressing outside the specified limits. RPA consider this requires that the monitoring and processing of the measurements be carried out by an independent organisation contracted to deliver the results to both RPA and the Contractor in an agreed format and to an agreed timescale.

The latter is the focus of this evidence since it is pivotal in demonstrating how RPA will ensure the works are executed correctly and safely. RPA require all relevant (but limited to what is relevant) amount of information that will allow RPA to monitor the impacts of tunnelling and excavation on buildings and infrastructure. Metro North will generate a huge amount of monitoring information, and therefore it is vital that the quantity of monitoring information received by RPA does not become so voluminous that the management, interpretation and assessment of this information overtakes the objective of reviewing the critical movement data that will be used to assess whether the works are being undertaken correctly and in a safe manner. Hence the emphasis is on limited but key safety critical information.

The information collected needs to be reliable and provided regularly on time. RPA will therefore use an organisation independent of the Contractor for installing, reading the instruments and processing the data collected during construction that is required to give RPA the assurance that the works are progressing within the specified tolerance or give sufficient warning that movements are progressing towards being outside the specified limits to enable corrective action to be taken. The required information will involve monitoring groundborne vibration, groundwater levels and making survey measurements of movements at ground level and on buildings and infrastructure, and will be commenced before construction starts in the vicinity of buildings and infrastructure that could potentially be affected. The instrumentation and monitoring arrays that have been used for baseline movement monitoring will also be utilised as part of this monitoring regime to ensure the works are undertaken safely and correctly. Generally such measurements would not interfere with the Contractor, although there will be situations where measurements would interface closely with the Contractor such as the use of inclinometers in diaphragm or bored pile retaining walls to monitor the behaviour of tunnels and excavations.

The application of the observational approach previously described by Professor Burland is extremely important to the instrumentation and monitoring regime proposed for Metro North. The response of the ground, and the structures founded

on it are observed as below ground construction progresses so that adjustments can be made to the design or method of construction if the observed response begins to depart significantly from the predicted response. The observational approach involves movements observed being compared with the design parameters and assumptions. If the observations differ significantly from the design, the reasons for the deviation will be investigated and the design and excavation sequence adjusted as appropriate. It should be noted that the Contractor is obligated by the contract specification to verify that actual recorded movements correlate with movements predicted by his detailed ground movement analysis otherwise corrective action is required to be taken. Frequently such adjustments involve a change in excavation procedure or technique. The key aspect of this approach is that the detailed monitoring permits the early identification of the unexpected behaviour and a quick and appropriate response. The principles of the observation approach are also set out in Eurocode 7, Part 1: Clause 2.7.

The contract specification also requires that detailed Instrumentation and Monitoring Plans that encompass the zone of influence, setting out the ground movement monitoring, building and infrastructure monitoring regime are developed by the Contractor and are in place before construction commences in the vicinity of buildings and infrastructure that could be affected. These are integrated with the Action and Contingency Plans that set predetermined action levels that will initiate the required contingency plans to prevent movements reaching maximum allowable values determined by the detailed ground movement analysis and building and infrastructure response assessment undertaken by the Contractor. Rate of change of levels will also be determined and taken account of by the Action and Contingency Plan. These Action and Contingency Plans will contain details of pre-determined remedial measures and corrective actions that will be applied in the event that the action trigger levels are exceeded. All these items will not only be designed by a competent designer experienced in this field of work, but will also be subject to a full independent design check as required by the construction contract.

These action trigger values will also be utilised by RPA to ensure the works are undertaken in a correct and safe manner, or will be used to identify corrective measures to be implemented, or ultimately if required the works to cease until the corrective measures proposed are to the satisfaction of RPA.

3 Role of the Independent Monitoring Engineer

As previously stated RPA needs to be in a position to be assured that the ground and associated building and infrastructure movements are within the specified tolerance and be given the earliest possible warning if movements are progressing outside of the specified limits. In addition RPA also need to be assured that the instrumentation and monitoring regime proposed by the Contractor to control the various geotechnical processes involved in tunnelling and excavation works is sound. This will firstly be achieved by independent checking of the instrumentation and monitoring designs, and secondly the Contract requires an Independent Monitoring Engineer and supporting organisation to be appointed. The Independent Monitoring Engineer and supporting organisation will have defined duties under the Contract, and will have a duty of care to RPA and the Contractor. He will be required to have demonstrable expertise in the field of instrumentation and monitoring of sub-surface works, and of any property that might be affected by these works. Duties to be undertaken shall include the review and approval of:

- (a) The identity and particulars of proposed organisations and persons involved with the undertaking of instrumentation and monitoring of the Works, including qualifications and experience of personnel to be employed.
- (b) All 'Plans of Action' and 'Response Actions' to be taken by the Contractor in the case of 'Response Values' being reached.
- (c) Proposed Response Values and Response Actions including instructing suspension of the works when required and approval of corrective actions and resumption of the works, and any proposed adjustment for prevailing conditions or circumstances.
- (d) All instrumentation to be used, quality documentation i.e. calibration certificates etc, method statements detailing installation and operation, pre-installation acceptance test record, records of instrumentation installation, and formal initial readings.
- (e) All instrumentation arrangements, configurations, installations and installation acceptance tests, instrumentation protection, as-built instrumentation location plans, including any extension of existing instrumentation installations.
- (f) Data collected, including its proposed monitoring frequency, format, presentation, interpretation and advising of corrections to be made.
- (g) Proposed soil sampling and testing to be undertaken, the storage of samples and the results of any testing undertaken.
- (h) Reinstatement required.
- (i) Any proposed deviations from this specification.

These duties placed upon the Independent Monitoring Engineer form part of a detailed instrumentation and monitoring specification provided to the Tenderers, Technical Note 025, Instrumentation and Monitoring, Example Specification provided under separate cover, that will be used to develop the instrumentation and monitoring regime for Metro North in conjunction with RPA.

4 Role of RPA and the Expert Panel

RPA is setting up an Expert Panel that will comprise of eminent industry recognised experts in specialist fields such as construction generated ground movements and building response. It is envisaged that Professor John Burland will be a member of this panel. The proposals to carry out the instrumentation and monitoring duties (including appointment of the Independent Monitoring Engineer) will be reviewed by the relevant qualified members of the Expert Panel before they are implemented to ensure they are appropriate.

A key role of the Expert Panel and RPA's geotechnical and tunnelling engineers will be in conjunction with the Preferred Bidder to:

- Review the appointment of the Independent Monitoring Engineer and supporting organisation.

- Develop the instrumentation and monitoring proposals in accordance with the Specification.
- Develop and agree management structure, key positions and associated levels of authority, and lines of communication between RPA, the Independent Monitoring Engineer and the Contractor with regards to ground movement monitoring.
- Review and agree proposed instrumentation and monitoring designs and plans for remaining baseline monitoring to be undertaken and movement monitoring during construction.
- Review and agree proposed Action and Contingency Plans.
- Agree key critical measurements to be provided to RPA to demonstrate works are being executed safely and correctly.
- Agree format and timescale for information to be provided to RPA.

RPA tunnel and geotechnical engineers will continue to oversee the instrumentation and monitoring work throughout construction to ensure it is being carried out in accordance with the proposals reviewed and agreed by the Expert Panel, as well as reviewing the monitoring data collected. RPA engineers will also be able to call upon relevant qualified members of the Expert Panel to consider any issues arising. In addition the Expert Panel will meet periodically to satisfy themselves that the work is being undertaken in a safe and competent manner. Any modifications made to the instrumentation and monitoring regime during construction will be scrutinized by RPA and the Expert Panel to the same degree as the initial monitoring proposals made.

In the unlikely event that the Expert Panel or RPA's geotechnical and tunnel engineers identify trigger values have been reached, or monitoring trends indicate that these will be reached imminently then RPA will reserve the right to take action, and if necessary instruct the safe cessation of that element of the works giving cause for concern until the corrective actions proposed are to the satisfaction of RPA.

5 Summary

RPA has a responsibility to ensure the works are executed correctly and safely. Movement monitoring information collected needs to be of high quality, reliable and provided regularly and on time to give RPA the assurance that the works are progressing within specified tolerance, or give sufficient warning that movements are progressing outside the specified limits to enable corrective action to be taken. To achieve this objective RPA requires this monitoring to be carried out by an Independent Monitoring Engineer and supporting organisation employed by, but independent of the Contractor with a duty of care to both RPA and the Contractor.

An Expert Panel employed by RPA comprising eminent industry recognised experts, including specialists such as Professor Burland with particular expertise in the fields of construction generated ground movements and building and infrastructure response is being created. The appointment of the Independent Monitoring Engineer, proposals to monitor the works by the Independent Monitoring Engineer and Contractor, development of the Instrumentation and Monitoring Plans and their integration with Action and Contingency Plans will be reviewed by the relevant qualified members of the Expert Panel to ensure they are appropriate.

RPA's geotechnical and tunnelling engineers will oversee the monitoring of the works, review and assess monitoring data collected and will be able to call upon the Expert Panel to consider any issues arising. In addition the Expert Panel will meet periodically to satisfy themselves that the works are being executed correctly and in a safe manner. In the event that the Expert Panel or RPA's geotechnical and tunnelling engineers consider that the works are not being undertaken in a safe manner, RPA will reserve the right to instruct the safe cessation of that element of the works giving cause for concern.

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