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Transport Infrastructure Ireland

Ground Movement Monitoring Information Paper

ML1-JAI-COM-ROUT_XX-PL-Z-00001| P03.1

2024/02/12

MetroLink

Project No:	32108600
Document Title:	Monitoring Information Paper.docx
Document No.:	ML1-JAI-COM-ROUT_XX-PL-Z-00001
Revision:	P03.1
Date:	2024/02/12
Client Name:	TII / NTA
Client No:	
Project Manager:	Paul Brown
Author:	P Wright / M Bowman / P Brown
File Name:	ML1-JAI-COM-ROUT_XX-PL-Z-00001 updated.docx

Jacobs Engineering Ireland Limited

Merrion House
Merrion Road
Dublin 4, D04 R2C5
Ireland
T +353 1 269 5666
F +353 1 269 5497
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checker	Reviewer	Approver
P01	14.03.23	First issue	PB	MG	MG	PB
P02	08.02.24	Second issue – updated for TII Comments	PB	MG	MG	PB
P03	11.02.24	Third issue – further clarify role of IME	PB	MG	MG	PB

Contents

1. Executive Summary

1.1 Information Paper Overview

This paper explains the strategy that will be adopted by TII to monitor, manage and thus control ground movements generated by MetroLink construction, drawing on the 'old Metro North' ground movement monitoring strategy upon which a Railway Order was granted. Pivotal to this strategy is the appointment of an organisation employed by the Contractor, termed the 'Independent Monitoring Engineer'.

The core purpose of the monitoring system is to ensure the safe construction of MetroLink. To do this, it is necessary to: confirm existing baseline ground characteristics so construction generated movements can be differentiated; verify design parameters and ground movement predictions, confirm the works and property are behaving as expected; provide advance warning of unacceptable movement trends; assist in determining whether movements have impacted property; and confirm when the risk of MetroLink generated movement has passed. All buildings and infrastructure, referred to as property hereafter, assessed to be potentially at risk of being adversely impacted by ground movements will be monitored.

1.2 Specification, Design and Implementation of the Movement Monitoring System

The Ground Movement Instrumentation and Monitoring Specification will be set out by TII's Client Partner. The specification will set out roles and responsibilities, and requirements including: instrumentation and monitoring; monitoring plans; reporting; information management (storage, provision of and access to data to required parties, including for external stakeholders and communities), and action plans and trigger values. The Contractor will be contractually obligated to comply with this specification and will be responsible for the design and undertaking of all movement monitoring.

1.3 Monitoring Phases and the Role of the Independent Monitoring Engineer (IME)

Monitoring will be undertaken in three phases:

1. **Baseline** – undertaken 3-12 months (depending on the duration over which construction is expected to occur) prior to construction generated ground movements occurring so that MetroLink construction impacts can be differentiated from existing movements.
2. **Construction** – the period extending from the commencement of excavation that may generate movement until immediate ground movements have ceased. During this phase there are two basic purposes for construction movement monitoring:
    i. Construction Control – the Contractor will need to control the various geotechnical processes involved in the tunnelling and excavation works and will be responsible for installing, reading and interpreting monitoring to check the behaviour of the ground, property and MetroLink structures are within acceptable limits. In the event movements are observed to differ significantly from the design, the reasons for the deviation will be investigated and the design and construction methodology adjusted as appropriate. The Contract will specify this observational approach and that detailed instrumentation and monitoring plans are in place and integrated with Monitoring Action Plans (MAP's). The key aspect of this approach is that monitoring enables the early identification of unexpected behaviour and the implementation of a rapid and appropriate response.

    Assurance and the Independent Monitoring Engineer (IME) **-** TII will require all information that will allow TII to monitor the impacts of tunnelling and excavation on property, and to be assured that the works are progressing as planned. To provide this assurance, it is proposed that the Contractor will employ an organisation called the Independent Monitoring Engineer (IME). The IME will be responsible for installing, reading the instruments and processing the data collected during construction that is required to give TII 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 role of the IME is pivotal in demonstrating how TII will ensure the works are executed correctly and safely.

It is important to recognise that MetroLink will generate a huge amount of monitoring information, and therefore it is critical the quantity of monitoring information received by TII does not overwhelm the management and interpretation of this information to assess whether the works are being undertaken correctly and in a safe manner. Hence the emphasis will be on limited but key safety critical information.

3. **Close-Out** - This post construction monitoring will continue until the rate of movement is no longer of significance or is not attributable to MetroLink construction. At this point the movement monitoring system will be decommissioned and any property to which instrumentation was attached made good.

1.4 Role of TII and the Expert Panel

To provide a further level of assurance, TII will have an Expert Panel in place that comprises of eminent industry recognised experts, including in the fields of geotechnics and construction. These experts will have a review and acceptance role that will cover: appointment of the IME; review of ground movement monitoring specifications; review of organisational design (management structure, responsibilities, levels of authority, key positions, and lines of communication (TII, IME, Contractor); and oversight of the design, including Monitoring Action Plans and the format and timescale for information to be provided to TII;

TII engineers will oversee the monitoring throughout the Construction phase to ensure it is carried out in accordance with Expert Panel direction, as well as being able to call upon the Panel for guidance, who will themselves meet periodically to review the works being undertaken. The Expert Panel and TII will also reserve the right to instruct the cessation of works in the event of issues arising giving cause for concern.

1.5 Monitoring Design

The monitoring design will be influenced by a number of factors, including: ground movement predictions and the assessed response of property; the condition, sensitivity, and historical, cultural or architectural significance of property; particular stakeholder requirements; agreements or conditions of the Railway Order; risk management; infrastructure criticality; and verification that movements are as expected.

The predominant method of monitoring will involve the optical surveying of fixed points on the ground or on property using precise levelling to measure vertical movement, and total stations with prisms to measure three-dimensional movement. This will be supplemented by tiltmeters with wireless sensors to remotely measure inclination and vertical rotation, inclinometers and extensometers to measures displacements, piezometers to measure groundwater levels, and crack monitors to measure crack width and propagation.

There are also “targetless” methods of monitoring available which do not entail the installation of fixings on property. Patch Scanning measures movement using electronic scanning while Interferometric Synthetic Aperture Radar (InSAR) measures movements using satellite or terrestrial imagery. InSAR is good for recording general ground movements. These methods may not always offer the same accuracy, frequency or reliability as more traditional monitoring techniques, but such methods may be appropriate to deploy where there are access issues, or to survey a wide area beyond the zone of influence to provide assurance.

The frequency of monitoring will depend on the phase of the works. Generally, it will be monthly where possible construction impact is greater than a month away, weekly one month before construction could have an impact, and then during construction it will comprise real-time, hourly, daily, several times a day and weekly depending on the rate of construction and the potential for movements to change.

The Contractor will be responsible for data management, storage, and distribution to the IME, TII and stakeholders. Manually collected and automated data will be generally available in a useable processed format within 6 hours, and 20 minutes respectively during the Construction phase. In the event a trigger level is reached, data will be made available as soon as possible and within 30 minutes of the readings being taken.

The Contract specification will also set out the requirement for trigger conditions and alarm protocols to be established, and Monitoring Action Plans (MAP) to be developed detailing responses to trigger levels. These will also comply with the procedures established by asset owners where such procedures exist.

1.6 Surveys to Inform the Instrumentation and Monitoring Design

Inspections and surveys, including condition surveys, will provide important information that will inform the ground movement response assessment, and the corresponding instrumentation and monitoring design.

All buildings and infrastructure that are identified as lying within the predicted ground movement zone of influence, will as a minimum be inspected externally (and internally where needed), assuming owner permission is granted, to ensure that any particular characteristics are identified. The information collected will be fed back into the ground movement response assessment and consideration given to whether further surveys and structural assessments should be undertaken to investigate particular characteristics. Condition surveys will also be undertaken in advance of the works commencing, subject to owner permission, to determine whether there has been any deterioration of property during the works that may be attributable to MetroLink, noting any such determination will also have a direct link to recorded movements.

Given the quantity of inspections and surveys to be undertaken, careful planning will be needed to ensure information is available in good time before construction commences. There is also an opportunity to rationalise the number of surveys given their synergy whilst still collecting the necessary information.

1.7 St Stephen's Green Exemplar Monitoring Design

To illustrate what could be required in terms of ground movement monitoring, an exemplar monitoring design has been developed (see Section 5 and Appendix A), based on the ground movement response assessment, for the area of the proposed St. Stephen's Green Station and the tunnel south of the Station.

For bored tunnelling, the principal monitoring will comprise precise surface levelling, supplemented by inclinometers, extensometers and piezometers where deep level asset monitoring is required, or for future research needs such as measuring the performance of structures and tunnels once MetroLink is operational or providing a source of data for future projects. For cut-and-cover station construction, the monitoring will comprise optical positional monitoring and inclinometers in diaphragm walls. To check groundwater levels, piezometers will be used.

For buildings the principal parameter to be monitored is vertical movement using precise levelling. Three-dimensional movement will be measured using prisms and total stations, and depending on the findings of surveys, other parameters such as cracking or tilt may also need to be monitored.

It is probable that the final Contractor-designed and installed ground movement monitoring system will vary from the exemplar reflecting that the MetroLink design will have undergone further development as well as being influenced by contractor preference. It is also possible that as a result of future stakeholder and community engagement, or findings from inspections and surveys, it may become apparent that selected internal movement monitoring of buildings is required for reasons such as the presence of specialist equipment, internal structures or finishes that are sensitive to movement.

2. Information Paper Purpose

2.1 Purpose

The purpose of this paper is to explain the proposed strategy and approach that will be taken by TII to monitor, manage and thus control ground movements generated by MetroLink construction. It is based on the ‘old Metro North’ ground movement monitoring strategy that was presented at the Oral Hearing and upon which a Railway Order was granted.

Given the approach taken to managing and controlling ground movements will be intrinsically linked to the MetroLink procurement strategy and schedule, as well as being critical to ensuring the safe construction of MetroLink within agreed environmental limits, it is the intention that this paper will provide a firm foundation upon which the MetroLink strategy for controlling and managing construction generated ground movements can be finalised. Of particular note is the use of an ‘Independent Monitoring Engineer’ and the role of the ‘Expert Panel’ (see section 3)

2.2 Scope of Paper

The paper will consider and explain:

- the MetroLink ground movement monitoring strategy, including why ground movement monitoring is necessary and how it will ensure MetroLink construction is executed correctly and safely;
- the monitoring phases and the area to be monitored;
- the role of the ‘Independent Monitoring Engineer’ and ‘TII and the Expert Panel’;
- how the ground movement monitoring system will be designed and what determines the design;
- summary details of instrumentation that may be used;
- an example of a typical movement monitoring arrangement that might be deployed for MetroLink to inform an understanding of what will need to be undertaken;
- consideration of the agreements that will need to be in place with various property owners to enable the installation, operation, maintenance and decommissioning of the ground movement monitoring system; and
- the role of property inspections, surveys and the Property Owners Protection Scheme (POPS) in this process.

3. Ground Movement Monitoring Strategy

3.1 Overview

The construction of MetroLink will involve tunnelling and excavation in an urban environment with its associated buildings and infrastructure. It is of note that a large proportion of the MetroLink construction will occur within the dense city built-up areas of Dublin, within and below Dublin Airport, and that ground conditions and the condition of buildings and infrastructure will vary. The response of the ground to MetroLink construction has the potential to influence the behaviour of the overlying and surrounding buildings and infrastructure.

The tunnelling and excavations are geotechnical processes that are controlled by the Contract specifications and the Contractor. This control is dependent on the design and construction methodology, and the response to the ground conditions and groundwater encountered, which will change as the geological conditions change and thus affect the degree of ground movement generated.

The following sets out the strategy and measures that will need to be instigated to monitor and control ground movements generated by tunnelling and excavation to ensure that the works are executed correctly and safely, taking account of the following considerations:

- Purpose and objective of ground movement monitoring.
- The ground movement impact assessments undertaken to date for buildings and infrastructure, along with the assessed risk and how this influences the design of the instrumentation and monitoring system.
- Phases of ground movement monitoring.
- The design and specification of the instrumentation and monitoring system, including relevant considerations, instrumentation likely to be used, and the extent of the area that will need to be monitored.
- Monitoring data – acquisition, processing, handling, storage, interpretation, sharing and distribution.
- Surveys needed to inform the design and support the operation of the instrumentation and monitoring system.
- The parties that will be involved in undertaking instrumentation and monitoring or with which there will be an interface.
- How TII will be assured that construction is progressing safely and as planned.
- The application of Monitoring Action Plans (MAP's).

3.2 Purpose and Objective of Ground Movement Monitoring

The core purpose of the designed instrumentation and monitoring system is to:

- Ensure the safe construction of MetroLink (construction control).
- Obtain “baseline” ground characteristics so construction generated movements can be differentiated.
- Verify design parameters and confirm the construction works, structures, tunnels, excavations and mitigation measures are behaving as designed.
- Verify buildings and infrastructure impacted by the works are behaving as expected.
- Provide advanced warnings of any unacceptable trends in ground movement or other parameters so that measures can be put in place to prevent issues arising.
- In the event of a claim by a third-party that movement has impacted their property, there is sufficient movement monitoring data available to assess that claim.
- Confirm when the risk of ground movement impacts has passed.

In addition, installed instrumentation and monitoring can be used to:

- Measure the performance of structures and tunnels once MetroLink is operational; and
- provide a source of data for future projects and research.

3.3 Instrumentation and Monitoring

Ground movement monitoring can be divided in to three key types:

i. MetroLink assets under construction - in-tunnel and structures monitoring (MetroLink construction control)
ii. In-ground monitoring
iii. Third party building, structures and utilities monitoring, and surface monitoring.

This Paper will focus on (ii) and (iii) as it is concerned with the interaction with third party property and ensuring TII can deploy a ground movement monitoring system to safely construct and deliver MetroLink but recognising (i) will also have a role to play in ensuring the safe delivery of MetroLink by drawing on key selected data used for construction control. For example inclinometers installed in diaphragm walls.

All buildings and infrastructure assessed to be potentially at risk from ground movements will be monitored. The type, duration, frequency and extent of monitoring will depend on the amount of ground movement predicted; the type of building or infrastructure; and agreements with property owners. The monitoring will vary from periodic levelling of settlement points to more extensive monitoring of horizontal and vertical movements.

The monitoring will be used to check that the behaviour of buildings or infrastructure are within acceptable limits as determined by the ground movement analysis. Any significant departure from the predicted response identified as tunnelling and excavation progresses will be fully analysed in order that appropriate contingency measures can be implemented, if deemed necessary, in good time to prevent unacceptable movement occurring.

Sections 4 and 5 provide further details of the type of ground movement instrumentation and monitoring equipment that may be utilised by the MetroLink Project and the design of the movement monitoring system. This will include consideration of the application of targetless / reflectorless systems (e.g., non-use of prisms that would normally be attached to buildings) on a case-by-case basis but noting that such systems are generally less precise and therefore careful consideration of their required performance and thus suitability will be necessary before determining whether a non-intrusive system is fit for purpose.

The design, installation, maintenance, decommissioning and monitoring of buildings and infrastructure will be undertaken by MetroLink contractors with the agreement of property owners, taking account of their particular requirements, as well as statutory requirements such as those associated with Protected Structures or as otherwise prescribed in the Railway Order as granted. The specific requirements for monitoring any third-party infrastructure and buildings will be determined from the assessment works carried out during detailed design and necessary surveys (see section 6). This will include inspections and surveys of all buildings and infrastructure that fall within the assessed movement monitoring area, plus condition surveys of all property within the movement monitoring area before any construction commences that could potentially impact the property concerned, followed by a post construction condition survey when ground movements have been shown to have ceased.

All property asset information that is collected will be stored in a central database and as it becomes available it will be reviewed against the ground movement impact assessment and inform the design of the instrumentation and monitoring system.

3.4 Movement Monitoring Area

Based on the ground movement impact assessment undertaken, the monitoring area will be defined by the 10mm and 1mm greenfield settlement contour. These will be the contours taken from the Contractor's

Stage 2B settlement analysis that is a verification of TII's Stage 2A analysis. The Stage 2 analysis is based on conservative parameters and empirical equations that overestimate the magnitude and extent of settlement, thereby ensuring that the extent of the movement monitoring regime is sufficient.

Generally, the movement monitoring area will be limited to designated buildings within the 10mm contour line, but buildings and infrastructure will be monitored by exception between the 10mm and 1mm contour line. Reasons for exception may include; a building or piece of infrastructure of particular historical, cultural or architectural significance, a building or piece of infrastructure that is particularly sensitive to movement, a critical piece of infrastructure, the result of a particular agreement with a property owner or to simply verify that measured movements are as expected, and to support and determine cause and effect on property in the event of a claim.

In addition selected transverse ground movement monitoring arrays that are perpendicular to the tunnel drive, or perpendicular to the wall of excavations will extend to the 1mm contour to validate the predicted settlement trough.

3.5 Movement Monitoring

The response of the ground, buildings, and infrastructure will be monitored for movement. This monitoring will be carried out in three phases, (Baseline, Construction and Close-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.

3.5.1 Baseline Movement Monitoring

A stable baseline ground movement pattern will be established prior to construction starting. Some existing ground movements may be identified due to seasonal, tidal and other natural or man-made changes. Baseline monitoring will allow any movements generated by Metrolink construction to be differentiated from existing ground movements.

TII's contractors (Early Works or Main Works depending on time available before Main Works construction commences) will undertake monthly baseline movement monitoring prior to work commencing where possible in areas where the MetroLink works could potentially have an impact. The duration of baseline monitoring required will vary and depend on the period over which movement generated during construction is expected to occur. For example, a cut and cover station box that is constructed over a period of several years, 12 months of baseline monitoring would be appropriate, whereas for a section of running runnel constructed by TBM, 3 months of baseline movement monitoring in advance of the tunnel would be considered adequate.

The buildings and infrastructure identified for baseline monitoring, along with durations, will be selected based on construction ground movement predictions.

The baseline monitoring will be expected to comprise of a combination of remote monitoring, levelling points and prisms placed external to buildings and infrastructure to enable vertical and three-dimensional moments to be recorded. There may also be an option to augment this monitoring with a satellite-based system to establish baseline movement seasonal changes. All baseline monitoring that requires access to buildings and infrastructure will need to be discussed and agreed with building and infrastructure owners.

In addition to the baseline monitoring of selected buildings and infrastructure, greenfield movement points will also be installed immediately beyond the proposed TBM launch site to enable the performance of the tunnel boring machine to be verified. It is also of note that baseline groundwater monitoring has already been undertaken to inform the EIAR and will be supplemented and monitored as necessary to inform the movement monitoring baseline.

In the event any of the baseline movement monitoring data is collected prior to the procurement or mobilisation of TII contractors, this information will be reviewed and assessed by TII's geotechnical and tunnelling engineers, and will be passed, when available, to TII's contractors to be taken account of in the design of the Construction phase monitoring system, along with any adoption of the baseline monitoring instrumentation previously installed to augment the Construction Phase monitoring system.

3.5.2 Construction Movement Monitoring

For the purposes of the Monitoring Strategy, Construction is the period extending from the commencement of excavation that may generate movement to the time at which the immediate ground movements due to excavation would have ceased. During this phase there are two basic purposes for construction movement monitoring:

1. Construction Control

The Contractor will need to control the various geotechnical processes involved in the tunnelling and excavation works and will be responsible for installing, reading and interpreting in-tunnel, in-ground and surface instrumentation and monitoring, which are required solely for these purposes. Typical examples of movement monitoring instrumentation that may be employed is discussed in Section 4 of this document.

For bored tunnelling, immediate ground movement typically occurs within hours following TBM passage beneath a monitoring point. For cut and cover works, sprayed concrete lined (SCL) tunnels, shafts, and ground support systems, the majority of ground movements occurs until the permanent structure is sufficiently complete to resist ground loads. Ground movement does continue after this period at a much reduced rate, mostly due to consolidation, and can therefore be monitored at a reduced frequency. There will be specified minimum requirements for when the Construction monitoring is to commence considering the aforementioned and would typically be as follows:

- Bored Tunnels – When the TBM is approaching a third-party asset, or control array, the construction monitoring period will commence 100m ahead of the TBM face. The construction monitoring period applying to any third-party asset will continue until it is clear that the immediate ground movement is complete. Typically, this is once the tunnel has progressed 50m beyond that asset. Thus, for TBM tunnelling the construction period relating to any monitoring point is unlikely to exceed 4 weeks for each tunnel drive.
- Other structures – cut and cover structures, shafts, and SCL works, will be considered sufficiently complete when the wall and/or lining elements are complete together with any permanent props or diaphragms, and immediate construction movements have ceased, at which point construction period monitoring will cease.

The instrumentation and monitoring regime will be designed to check the behaviour of the ground, buildings and infrastructure are within acceptable limits, as determined by the ground movement impact assessment analysis. Where movements are observed to differ significantly from the design, the reasons for the deviation will be investigated and the design and construction methodology will be adjusted as appropriate.

The Contractor(s) will be obligated by the contract specification to adopt this observational approach and verify that actual recorded movements correlate with movements predicted by their detailed ground movement analysis, otherwise corrective action is required to be taken. The key aspect of this approach is that detailed monitoring permits the early identification of unexpected behaviour and implementation of a rapid and appropriate response.

The Contract specification will also require that detailed Instrumentation and Monitoring Plans defining the ground, building and infrastructure monitoring regime are developed by the Contractor(s) and are in place before construction commences in the vicinity of buildings and infrastructure that could be affected. These Plans will be integrated with Monitoring Action Plans (MAP's) that set predetermined action trigger levels that will initiate the required contingency plans and remedial measures to prevent movements reaching maximum allowable values determined by the ground movement analysis and response assessment undertaken by the Contractor(s), and thus provide TII with the assurance the works will be undertaken in a correct and safe manner.

All these items will not only be designed by a competent designer experienced in this field of work but will also be subject to full independent design checks as required and overseen by the Independent Monitoring Engineer (see 3.6 below).

2. **Assurance**

TII will require all information that will allow TII to monitor the impacts of tunnelling and excavation on buildings and infrastructure and to be assured that the excavations and tunnels, ground, groundwater levels, and associated building and infrastructure movements are within the specified tolerance as well as being given the earliest possible warning of movements that are progressing outside the specified limits.

Based on the approach taken for 'old Metro North', it is proposed the Contractor will employ an organisation independent of the construction / production team (the Independent Monitoring Engineer) to ensure that the instrumentation and monitoring system is designed, installed and can be operated, including the reading and collection of data, in an agreed format and to an agreed timescale, to provide the Contractor(s), TII and building and infrastructure owners with 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. This will be pivotal in demonstrating how TII will ensure the works are executed correctly and safely. The responsibilities of the independent Monitoring Engineer are expanded on in section 3.6.

MetroLink will generate a huge amount of monitoring information, and therefore it is vital that the quantity of monitoring information received by TII does not become overwhelming so 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 required information collected by the Independent Monitoring Engineer will involve making survey measurements of movements at ground level and on buildings and infrastructure, and access to inclinometer data in diaphragm or bored pile retaining walls to monitor the behaviour of cut and cover tunnels and excavations.

In addition to 'The Independent Monitoring Engineer', TII will also set up an 'Expert Panel' (see section 3.7). Both of these organisations will play a key role in assuring the works are constructed safely and to plan.

During the Construction phase, the frequency of this assurance monitoring will be a combination of real-time monitoring, and daily and weekly manual monitoring (e.g., levelling). With monitoring frequency increasing depending on the rate of construction and an assessment of the potential for movements to change.

3.5.3 Close-Out Monitoring (Post-Construction)

The post-construction period follows the construction period as defined above. The post-construction period will continue until the rate of movement is no longer of significance or is not attributable to MetroLink construction. It is envisaged that the duration for Close-Out monitoring after the construction period will not be less than three months, with the frequency of readings reducing as movements stabilise until there is no risk of detrimental impact posed to buildings and infrastructure. At this point the movement monitoring system will be decommissioned and the building or infrastructure with which it was associated made good.

3.6 Specification of Ground Movement Monitoring

The Ground Movement Instrumentation and Monitoring Specification will be drafted by TII's Client Partner. This specification would be expected to include and set out:

- The instrumentation and monitoring strategy.
- The roles and responsibilities of the IME and the Contractor and their personnel; and how conflict of interest is to be avoided between the two roles.
- The roles and responsibilities of TII and their consultants, and the Expert Panel.
- Instrumentation and monitoring requirements and specifications.
- Monitoring plans.
- Movement monitoring reporting requirements.
- Baseline, Construction and Close-out monitoring requirements.
- Interfaces with others E.g. TII, Expert Panel, IME, stakeholders, community groups.
- The information that is to be provided to the IME by the Contractor that will in turn provide the assurance to TII, building and infrastructure owners that the works are progressing within the specified tolerance.
- Instrumentation and monitoring data handling and storage (including database), and access to data, including stakeholders and community groups, as well as TII, Expert Panel and the IME.
- Action Plans and Trigger Values.

3.7 Role of The Independent Monitoring Engineer

The Contractor(s) will remain responsible for designing the monitoring, monitoring and managing the impact of the Works on all third-party assets. The Independent Monitoring Engineer will be an independent organisation employed by the Contractor for the Construction monitoring phase who will:

1. Provide assurance to TII that the ground and associated building and infrastructure movements are within the specified tolerance and provide the earliest possible warning if movements are progressing outside of the specified limits.

   The IME will be responsible for installing, reading the instruments and processing the data collected during construction that is required to give TII 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.

2. Provide assurance to TII that the instrumentation and monitoring regime proposed by the Contractor(s) to control the various geotechnical processes involved in tunnelling and excavation works is fit for purpose.

3. Other Duties to be undertaken by the IME shall include the review and acceptance of:

   - proposed organisations and persons involved with the design and undertaking of instrumentation and monitoring, proposed by the Contractor(s).
   - the ground movement instrumentation and monitoring system.
   - Action and contingency plans to be deployed.
   - Proposed trigger levels that will enact action and contingency plans (Monitoring Action Plans), including suspension and securing of the works when required, and approval of corrective actions and resumption of the works, and any proposed adjustment for prevailing conditions or circumstances.

- Instrumentation to be used, quality documentation i.e. calibration certificates etc., method statements detailing installation and operation, pre-installation acceptance test records, records of instrumentation installation, and formal initial readings.
- All instrumentation arrangements, configurations, installations and installation acceptance tests, instrumentation protection, as-built instrumentation location plans, including any extension of existing instrumentation installations.
- Data collection and storage, including proposed monitoring frequency, format, presentation, interpretation, distribution and advising of corrections made.
- Reinstatement and making good proposals.
- Any proposed deviations from the instrumentation and monitoring specification if agreed by TII.

These duties placed upon the Independent Monitoring Engineer will form part of the instrumentation and monitoring specification provided to the Contractor(s) at tender stage.

3.8 Role of TII and the Expert Panel

TII will set up an Expert Panel that comprises of eminent industry recognised experts in specialist fields such as construction generated ground movements and building and infrastructure response. 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.

The key roles and responsibilities of the Expert Panel and TII's geotechnical and tunnelling engineers will be:

- Review the ground movement instrumentation and monitoring specifications that will form the basis of the contracts with the Contractor(s).
- Review the appointment of the Independent Monitoring Engineer and any supporting organisations or personnel.
- Agree the management structure, key positions and associated levels of authority, and lines of communication between TII, the Independent Monitoring Engineer and the Contractor(s) with regards to ground movement monitoring.
- Review and accept proposed instrumentation and monitoring designs and plans for Baseline and Construction Phase monitoring.
- Review and accept proposed action and contingency plans (Monitoring Action Plans).
- Agree the format and timescale for information to be provided to TII.

TII tunnel and geotechnical engineers will continue to oversee the instrumentation and monitoring work throughout the construction phase 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. TII 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 scrutinised by TII and the Expert Panel to the same degree as the initial monitoring proposals made.

In the unlikely event that the Expert Panel or TII's geotechnical and tunnel engineers identify trigger values have been reached, or monitoring trends indicate that these will be reached imminently, then TII 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 TII.

3.9 Stakeholders, the Community, Building and Infrastructure Owners

It will be important to engage and keep the community and property owners (buildings and infrastructure) informed of why and how the areas that lie above and around where tunnelling and sub-surface excavation is taking place will be monitored for movement, and what will take place over the duration of the three monitoring phases (Baseline, Construction and Closeout).

Infrastructure owners will likely in many cases have their own view of the monitoring that should be undertaken and this will need to be agreed and incorporated into the movement monitoring regime. It is also likely they will want to agree instrumentation and monitoring plans in advance, the associated action and contingency plans (Monitoring Action Plans) and be presented with relevant monitoring data so they can be assured their infrastructure is safe and being looked after.

For building owners, the Contractor and TII will need to provide updates on the progress and performance of the works to assure building owners the works are progressing safely and in accordance with the design.

In all cases it will be necessary to agree access arrangements (external and internal) for installing, measuring, maintaining and decommissioning monitoring instrumentation. Infrastructure owners will in general be well informed of the need for and required monitoring arrangements. For building owners, it will be important to inform and provide the assurance of why monitoring is necessary, allay any concerns, and demonstrate that it will be managed competently, and their interests will be taken care of. This will include in all cases fixing details and reinstatement proposals.

4. Ground Movement Monitoring Instrumentation and Systems

This section provides an overview of the typical instrumentation that is likely to be used to monitor the ground, building and infrastructure movements that will occur during the construction of the MetroLink works. In summary this instrumentation includes:

- **Building and surface settlement points –** measures vertical and three-dimensional movements using optical surveying techniques.
- **Tiltmeters** – measures inclination and vertical rotation of structures.
- **Inclinometers** – measures small changes in vertical level and horizontal movement of the ground or structures.
- **Piezometers** – measures groundwater levels.
- **Extensometers** – measures vertical displacements in the ground.
- **InSAR** – measures movements using satellite or terrestrial imagery (reflectorless technique).
- **Patch Scanning** – measures movement using electronic scanning (reflectorless technique).
- **Crack Monitors** – measures crack widths and their propagation.
- **Specialist utility monitoring**

4.1 Building and Surface Settlement Points

It is proposed to monitor the facades of buildings and structures for three-dimensional movement using reflective prisms (Figure 4-1) bolted into the building or structure. These targets are then read by automatic total stations (ATS) surveying instrumentation that measures angles and distance to pinpoint the prism to within $\pm$2mm three dimensionally. Where it is not possible to attach such instrumentation to a building or structure, for example a glass faced building or a building of cultural or historical significance, alternative methods such as stick on targets or reflectorless monitoring techniques will be used.

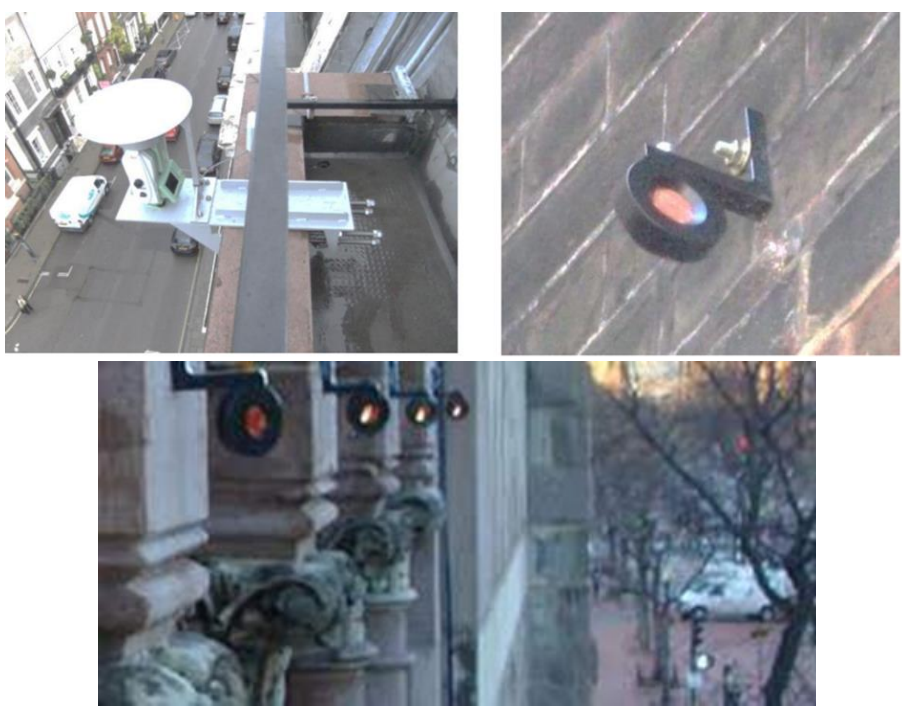


Figure 4-1 Examples of Total Station (left) and Prism (right)

Where vertical settlement values are only required, threaded sockets of the Building Research Establishment (BRE) socket type will be fixed to buildings or structures, or attached to a rigid bracket clamped to a steel structure (see Figure 4-2 below). A bolt or shoe is then attached by the surveyor to measure vertical movement to ±1mm accuracy using an optical precise levelling machine. Where it is not possible to attach such instrumentation to a building or structure, alternative methods such as stick on targets or reflectorless monitoring techniques will be used.

Figure 4-2 BRE Socket and Precise Levelling

To measure ground movement in paved areas, markers comprising of nails or pins (see Figure 4-3) will be hammered or drilled into the surface. The surveyor will record measurements using an optical precise levelling machine to enable settlement readings up to ±1mm accuracy.

Figure 4-3 Road or Pavement Nail / Pin

Where movements are to be monitored in open ground, ground markers will be installed (Figure 4-4). Typically, these comprise a dug hole circa 0.2m x 0.2m x 0.4m deep, filled with concrete to approximately 0.2m below the ground surface into which a corrosion resistant c.70mm domed metal pin is fixed with epoxy resin. The levelling point may also have a cover to prevent it from being disturbed.

Figure 4-4 Typical Ground Markers

4.2 Tiltmeters

Some movement monitoring needs to be undertaken remotely to avoid disruption to services and placing persons undertaking the monitoring at risk. Examples of such include railway track, and airport runways and taxi ways. Tiltmeters are often used for this reason.

Tiltmeter units have wireless sensors to enable measurements to be taken remotely and can be installed quickly to provide precise measurement for many years after installation. The data collected can be used to evaluate the effectiveness of interventions such as tamping of railway track, to determine whether pre-identified movement has stabilised or is ongoing, and to identify movement trends and the risk of movement trigger levels being reached.

For railways (Figure 4-5), a wide range of track geometry defects and parameters can be measured, including cross-level, twist, slew, settlement and temperature. Sensors are usually fixed to track ties but can also be mounted on other track assets such as gantries, platforms and undertrack culverts. This type of wireless monitoring can provide an alternative or a supplementary approach to optical methods such as robotic total station or Automatic Motorised Total Station (AMTS) monitoring.

Figure 4-5 Typical Rail Tiltmeter Installation

4.3 Inclinometers

Inclinometers are installed in lined boreholes (see Figure 4-6) and are used to measure very small changes from the vertical level, either of the ground or in structures E.g., diaphragm or secant pile walls. Accuracy of readings is ±10mm in 30m when the casing is installed within 3 degrees of vertical.

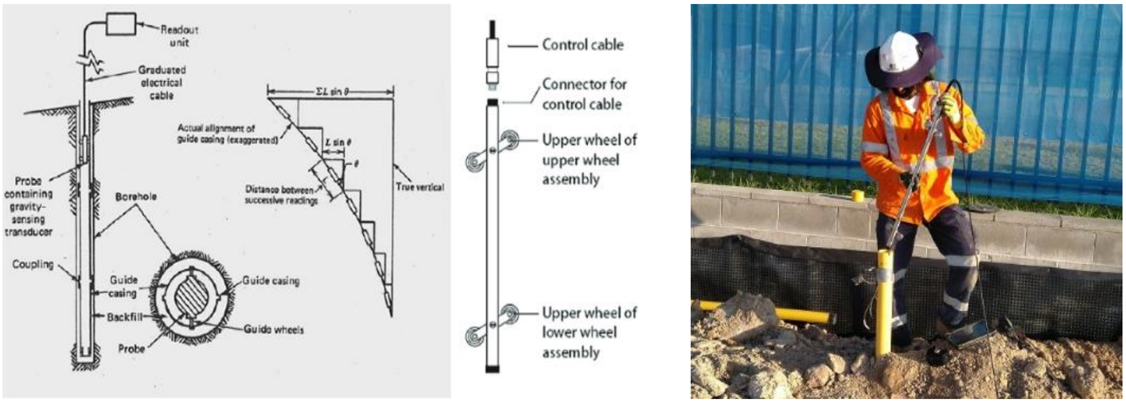


Figure 4-6 Inclinometer

4.4 Piezometers

Piezometers are used to measure groundwater levels (see Figure 4-7). They are installed in drilled boreholes set to the required depth. A porous standpipe is wrapped in a geotextile fleece and inserted into the borehole, and sand gravel material is then placed between the standpipe and the borehole. It is then sealed at the top and a protection box is then located over the installation. At predetermined intervals a surveyor will lower a probe down the standpipe to measure the depth to the water surface to an accuracy of <0.5%.

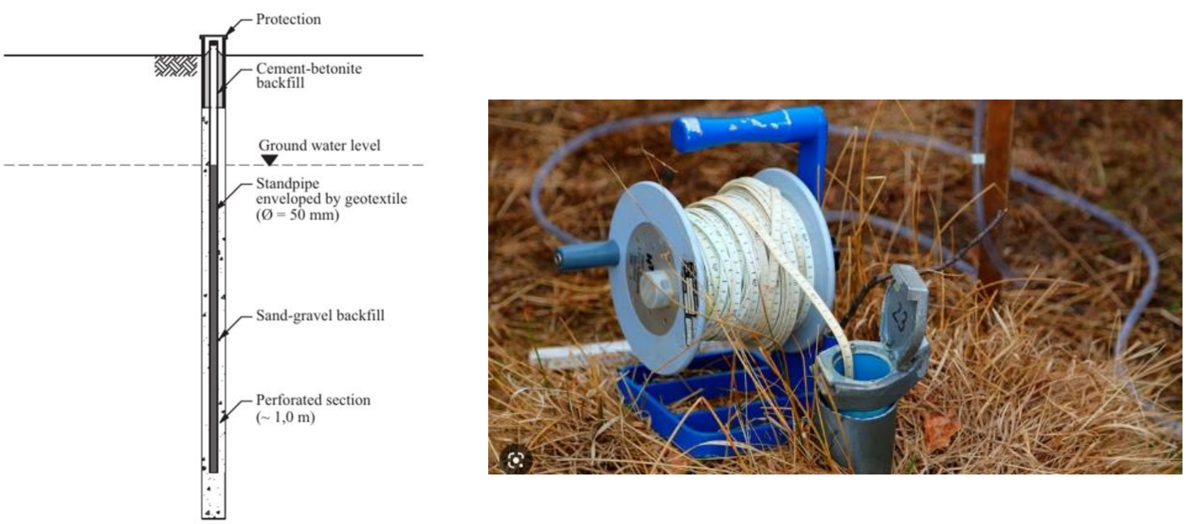


Figure 4-7 Open Standpipe Piezometer

4.5 Extensometers

Extensometers are used for measuring displacements in the ground (see Figure 4-8). The most common forms are probe (magnet) extensometers and rod extensometers. Rod extensometers are most frequently used for tunnel settlement monitoring. They consist of hydraulically operated anchors, connecting rods and a measuring head. Each anchor is positioned where a measurement is required and joined to a connecting rod, which runs to a measuring head located at the ground surface. Measurements can be recorded manually using a dial gauge or precise level, or automatically using an electric displacement transducer. Typical system accuracy is ±2mm.

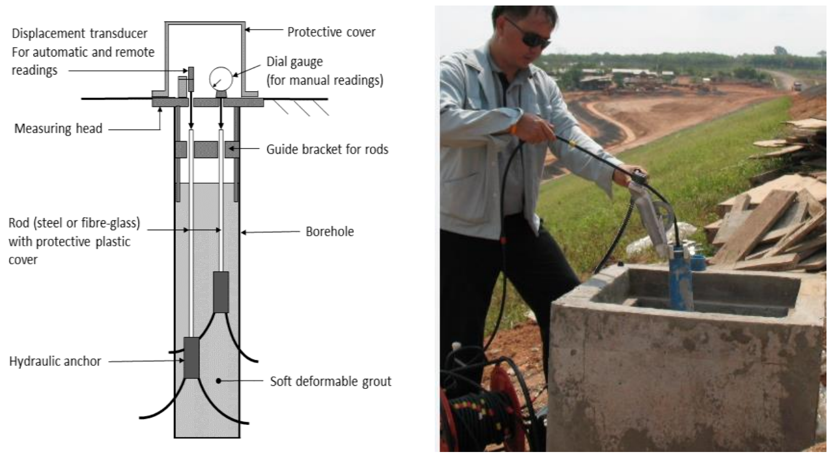


Figure 4-8 Extensometer

4.6 InSAR

Interferometric Synthetic Aperture Radar (InSAR) detects and measures displacement over time. The technology is based on the comparison of multiple radar (SAR) image pairs captured by satellite (Figure 4- 9), which are then used to create interferograms and compare two SAR images. The difference in the wavelength's phase denotes the amount of displacement that took place between the image acquisition dates. Processing techniques are employed to remove contaminant signals such as atmosphere, and ultimately, the displacement results are presented visually over optical satellite imagery so one can easily interpret what locations are moving, by how much, and when.

The advantage of this type of monitoring is that it requires minimal equipment to be installed and is good for recording general ground movements to establish background movement baselines or providing supplementary movement data. It does however rely on the reflective nature of the urban area and therefore some infrastructure may be difficult to obtain readings from. Movement readings of up to +1mm accuracy can be achieved. The frequency of readings varies but typically once every 2 to 12 days and therefore it is not suitable for construction phase monitoring where real time monitoring or a high frequency of readings is required.

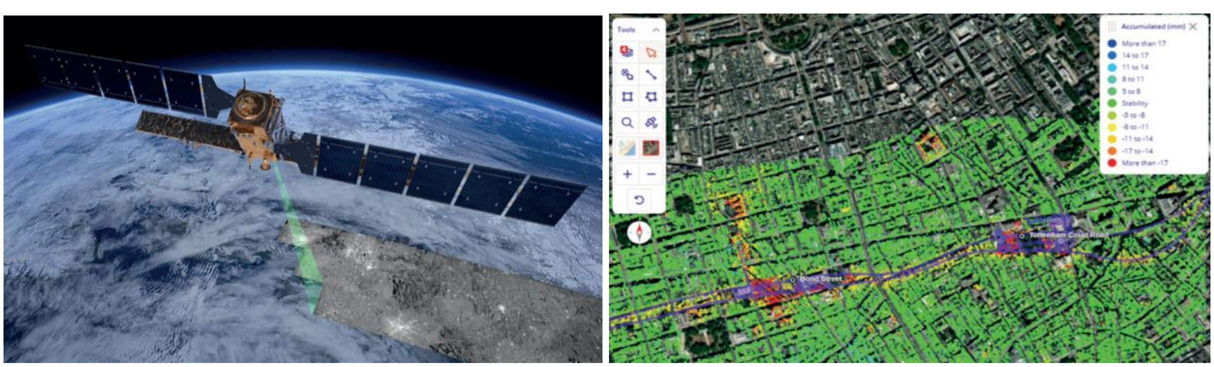


Figure 4-9 InSar Monitoring

4.7 Patch Scanning

It may be possible to monitor some buildings and infrastructure using unintrusive scanning techniques (See Figure 4-10). Similar to InSar the information obtained can be processed by software which provides a highly flexible automatic deformation monitoring system. The advantage is that no monitoring equipment needs to be attached to the structure although the scanners have to be fixed on a solid structure within line of sight.

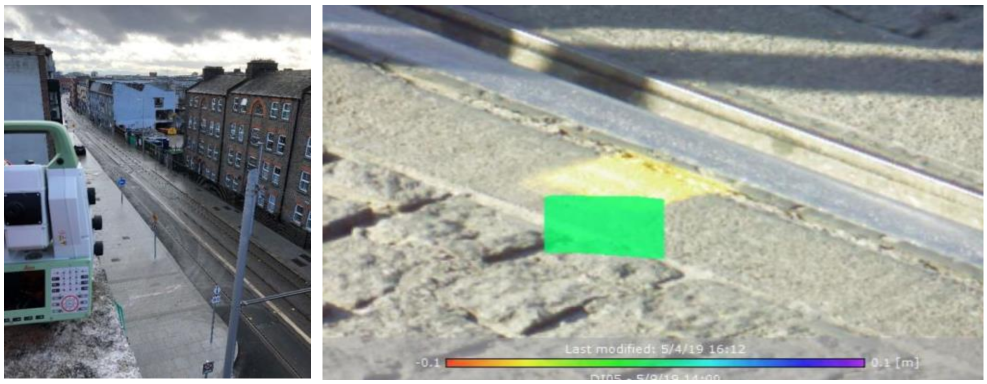


Figure 4-10 Patch Scanning the Luas Line (highlighted green rectangle shows difference in movement from previously captured image)

4.8 Crack Monitors

When cracks within a structure become significant these can be monitored using crack meters (see Figure 4-11). These are simply glued to the structure across the crack and manually read at agreed intervals to the nearest millimetre.

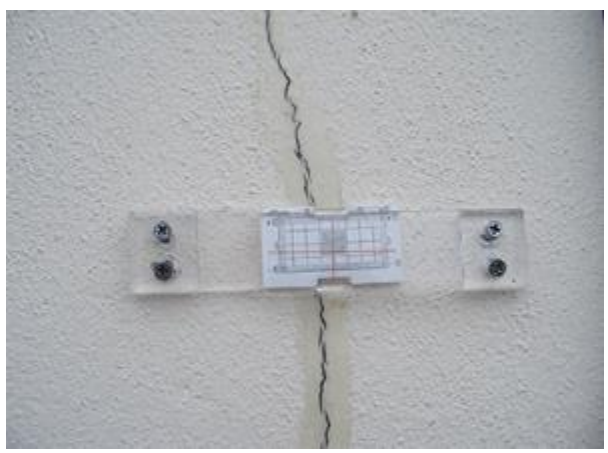


Figure 4-11 Crack Meter

4.9 Specialist Utility Monitoring

Movement monitoring of utilities is achieved by monitoring the ground in the vicinity of the utility typically using optical levelling techniques (road or pavement nail / pin or ground markers), possibly supplemented by inclinometers and extensometers. In addition, the following may be employed, typically by the relevant statutory undertaker:

- Gas mains – where an old or fragile main may be expected to experience significant movement, sniffer testing may be undertaken. This involves drilling small holes in the surface above the main. At pre-determined frequency a gas monitor probe is inserted down these holes to check there is no evidence of gas leakage.

- Sewers - where accessible, can be monitored by laser scanning from within the structure and by installing Shape Accelerator Arrays (SAA), a chain of rigid segments connected by flexible joints. (See figure 4-12). Each segment is instrumented with three orthogonally mounted tilt sensors and a microprocessor and is attached to the structure using proprietary fixings at circa 200mm centers to measure three-dimensional movement to an accuracy of ±1.5mm.

Figure 4-12 Shape Accelerator Array

- Water Mains - can be monitored for leakage using pressure management systems which are installed in access pits. The information is then transmitted wirelessly to a central management center for analysis. Alternatively, a small hydrophone listening device can be fitted to an existing fire hydrant with no excavation works required. Figure 4-13 shows examples of these systems.

Figure 4-13 Pressure Management System and Hydrophone

5. Ground Movement Monitoring Design

5.1 Design of the Ground Movement Monitoring System

In this section the principles upon which the design of a ground movement instrumentation and monitoring system is founded on are described, including: typical monitoring arrangements that are employed to determine the effects of construction; expected frequency of monitoring readings; management of monitoring data; and the application of action and contingency plans. An exemplar movement monitoring design in the area of St Stephen's Green is also provided to illustrate how these principles are applied and the objectives set out in Section 3, in particular, to ensure the safe construction of i MetroLink and that the interests of building and asset owners are safeguarded will be met.

The ground movement monitoring design is informed by a number of factors, including:

- construction ground movement predictions;
- the assessment of the response of buildings and infrastructure to movements;
- the condition, sensitivity and historical significance of buildings and infrastructure;
- particular stakeholder requirements, agreements or conditions of the Railway Order;
- risk management (including high impact low probability events); and
- criticality of the asset. For example, an asset such as a railway mainline, trunk sewer, airport taxiway would if impacted unacceptably have a disproportionate wider impact.

The monitoring arrangements set out assume that tried and tested monitoring techniques and instrumentation is used, in particular optical monitoring using prisms and robotic total stations, and precise levelling, supported by piezometers, extensometers and inclinometers. These methods entail the physical installation of monitoring points, on buildings and infrastructure, on the ground surface and on structures forming the new underground assets. However, as previously discussed, there are other "targetless" or "reflectorless" methods of monitoring which do not entail the physical installation of equipment such as InSar and patch scanning (see section 3). These methods may not always offer the same accuracy, frequency or reliability of data however, so caution is advisable when specifying such equipment, but such methods may be appropriate to deploy in place of target-based systems where there are access issues and/or where they are technically acceptable.

5.2 Monitoring for Determining the Effects of Construction

5.2.1 Monitoring of the Construction Process

While this section focusses most specifically on the design of monitoring to verify and protect buildings and infrastructure along the Metrolink route, it is important to first consider the monitoring of the construction process itself, as control of the construction process is what determines the magnitude of ground movement, and hence the monitoring design that will be used to verify the predicted effects of construction.

For tunnelling, the principal monitoring will comprise surface levelling, subsurface extensometer, inclinometer and piezometer measurements at Control Sections perpendicular and in-line with the tunnel. These Control Sections are to be located, where possible in open ground, early in the tunnelling operation and at key positions before a tunnel encounters sensitive assets or asset groups. Surface levelling points along the centreline of the tunnel may be combined with other functions such as monitoring road levels for instance. Table 5-1 summarises these monitoring requirements and also cross refers to the exemplar locations at St Stephen's Green shown on the drawings in Appendix A that are described in further detail in section 5.6.

Table 5-1 - Summary of Monitoring Requirements Specifically for Determining the Effects of Tunnelling

Requirement	Parameter Monitored	Equipment Location	Monitoring Equipment	Equipment Shown on Appendix A Exemplar Drawings
Monitor ground surface movement, especially level.	x,y,z coordinates	Key locations; directly above the tunnel and lateral lines.	Mini-prism and precise level.	Mini-prism and precise level point.
Monitoring ground surface movement at extensometer and inclinometer positions.	x,y,z coordinates	Top of Extensometers and inclinometers.	Mini-prism	Mini-prism
Monitoring of lateral displacements; automated readings and transmission.	Lateral displacement	Key locations; at the points of inflection of the Zone of Influence of the tunnel.	Inclinometer	Inclinometer (in Control Sections)
Monitoring vertical ground movements within ground; automated readings and transmission.	Settlement at depth in increments	Key locations; directly above the tunnel.	Extensometer	Extensometer (in Control Sections)
Monitoring ground level at extensometer and inclinometer positions.	Level	Top of extensometers and inclinometers.	Precise Level	Precise Level (in Control Sections)
Monitoring water levels in the vicinity of the tunnels; automated readings and relay.	Level	Key locations; directly above the tunnel and lateral lines.	Piezometer	Piezometer
Monitoring of natural background movement before and after the works.	Level	Area wide.	InSAR	Targetless/reflectorless technique not used by the exemplar design.

For cut-and-cover and other groundworks such as cuttings and embankments, the monitoring will comprise optical positional monitoring and inclinometers in diaphragm or secant pile walls. Table 5-2 summarises these monitoring requirements and also cross refers to the exemplar locations at St Stephen's Green shown on drawings in Appendix A that are described in further detail in section 5.6.

Table 5-2 - Requirements Specifically for Determining the Effects of Station Box Excavation

Requirement	Parameter monitored	Equipment Location	Monitoring Equipment	Equipment Shown on Appendix A Example Drawings
Monitor diaphragm/secant wall.	x,y,z coordinates	On top of wall, and at lateral support positions.	Mini-prism	Mini-prism
Monitor diaphragm/secant wall.	Level	On top of wall.	Precise Level	Precise level point.
Monitor ground surface movement, especially level.	x,y,z coordinates	In lines perpendicular to wall	Mini-prism and precise level.	Mini-prism and precise level point.
Monitoring of lateral displacements; automated readings and transmission.	Lateral displacement	Key locations; installed in diaphragm / secant wall panels	Inclinometer	Inclinometer (installed in wall).

Requirement	Parameter monitored	Equipment Location	Monitoring Equipment	Equipment Shown on Appendix A Example Drawings
Monitoring of lateral displacements; automated readings and transmission.	Lateral displacement	Key locations; In lines perpendicular to wall	Inclinometer	Inclinometer (installed in ground).
Monitoring ground surface movement at extensometer and inclinometer positions.	x,y,z coordinates	Top of extensometers and inclinometers.	Mini-prism	Mini-prism
Monitor water levels in the vicinity of the excavation; automated readings and relay.	Level	Key locations; In lines perpendicular to wall	Piezometer	Piezometer
Monitoring of natural background movement before and after the works.	Level	Area wide	InSar	Targetless/reflectorless technique not used by the exemplar design.

A key aspect of the design is to maintain ground water levels in line with the natural groundwater profile during the construction process so far as is reasonably practicable, since changes in the groundwater level can cause shrinkage and expansion of the subsurface soils. To check groundwater levels, independently from the tunnelling and other groundworks, a series of piezometer positions along the route, where the water table is expected to be above the tunnel, will be selected. Currently, such positions are proposed at approximately 500m intervals for tunnelling, but will be more frequent in urban settings, at Control Sections and adjacent to cut and cover excavations for stations.

It is anticipated that this construction monitoring will show that the actual ground movements are less than the predicted ground movements. In the event that significant deviation from the predicted movements is detected, this will be managed using predetermined Monitoring Action Plans (see section 5.5).

5.2.2 Monitoring of Buildings General

The standard method of assessing building damage follows the guidance of Burland et al (1977) and Boscardin and Cording (1989) as set out by the 'MetroLink Damage Assessment Report of Buildings and Other Assets.' This document explains how the assessment has been carried in two stages; firstly an initial Phase 2a damage assessment using very conservative ground movement assumptions, and secondly a more reasonable but still conservative refined damage assessment. The initial assessment identified only nine buildings which fell into risk category 3 (moderate), and those nine buildings all went into risk category 2 (slight) for the refined assessment.

In the context of the building damage assessment, 'special' considerations refer to buildings (hereafter referred to as 'special' buildings) in proximity of the excavation, with deep basements and those identified as protected or sensitive buildings as defined below:

- Case A: it is on shallow foundations and is within a distance from a retained cutting, shaft or box equal to the excavated depth of superficial deposits or 50% of the total excavation depth, whichever is the greater. In this context, superficial deposits are taken to be soils above the rockhead level;
- Case B: it has a foundation level deeper than 4m, or (in the case of a bored tunnel) greater than 20% of the depth to tunnel axis;
- Case C: it is a Protected Structure;
- Case D: any 'prominent' or 'sensitive' buildings that might need further assessment to determine whether any protective works are required.

Out of nearly three hundred buildings assessed, the MetroLink Damage Assessment Report of Buildings and Other Assets identified 94 No. buildings passing to Phase 3 damage assessment. These buildings will need detailed assessment. All but one of the buildings which pass to Phase 3 in the refined assessment do it solely for the reason of their “special” character e.g. legal protection, sensitivity or foundation details. It is considered that all the buildings passing to the Phase 3 assessment would undergo some form of movement monitoring.

The “non-special” buildings which reside in Category 2, and therefore do not qualify for a Phase 3 assessment, will in general not be monitored specifically, but will form part of a wider movement monitoring regime to verify the works are proceeding as planned.

The principal parameter to be monitored is settlement. However, measurement of the smaller horizontal movements will also be necessary for many buildings to understand the strain that the buildings are experiencing. Depending on the findings of the condition surveys, other parameters such as cracking or tilt may need to be monitored. Table 5-3 summarises these monitoring requirements and also cross refers to the exemplar design for St Stephen’s Green summarised on drawings in Appendix A that are also described in further detail in section 5.6.

Table 5-3 - Requirements Specifically for Determining the Effects of Construction on Buildings

Requirement	Parameter monitored	Equipment Location	Monitoring Equipment	Equipment Shown on Appendix A Example Drawings
Monitor building movements.	x,y,z coordinates	Typically, at corners and at intervals along the building at 3 levels.	Mini-prism	Mini-prism
Monitor building/ground settlement.	Level	On base or foot of walls or boundary walls adjacent to building.	Precise level	Precise level point.
Monitor movement of Protected Structures or architecturally significant buildings and structures.	x,y,z coordinates	Remote from building.	Reflectorless technique such as patch or terrestrial InSAR.	Mini-prism and precise levelling.
Monitor baseline behaviour and confirm construction movement over long term.	Level	Satellite	InSAR or similar.	Targetless/reflectorless technique not used by the exemplar design.
Monitor building cracking.	Crack width.	On crack if formed.	Crack-meter	Not shown. Will be determined by inspections and surveys.

5.2.3 Protected Structures

Protected structures will be subject to the same monitoring requirements as other buildings (Table 5-3), although there may be additional requirements to avoid fixings on buildings, whilst recognising and balancing this with the limitations of reflectorless systems as previously highlighted. The intensity and frequency of the monitoring may also be increased, and where appropriate, conservation specialists will need to be consulted to ensure the design of the monitoring system is compatible with protecting the building or structure that is to be monitored.

5.2.4 Exceptional Assets and Structures

Strategic Utilities

The monitoring of specific strategic utilities will be agreed with the statutory undertaker on a case-by-case basis to suit operational requirements using the instrumentation and techniques described by section 4.9.

Buildings in Poor Condition and Unexpected Internal Arrangements,

Buildings and infrastructure in poor condition or that have unexpected internal arrangements e.g., swimming pools, basements, internal temporary propping etc. will only become apparent on completion of inspections and surveys. It will therefore be necessary to undertake these inspections and surveys in good time to allow their results to be fed into the ground movement impact assessments and the subsequent design and installation of the instrumentation and monitoring system. These surveys and inspections are discussed further in section 6.

Bridges and Viaducts

The monitoring of bridges will be agreed with the bridge owner and other stakeholders on a case-by-case basis to suit operational requirements and will be expected to comprise mini-prisms and precise levelling points to measure x,y,z and vertical position respectively, supplemented by remote monitoring techniques such as tiltmeters and patch scanning.

5.2.5 Utilities

Monitoring requirements will be agreed with the utility owners and would be expected to generally comprise of that described by Table 5-4, whilst noting there will be a need for specialist monitoring of strategic utilities (see 5.2.4).

Table 5-4 - Summary of Monitoring Requirements for Strategic Utilities

Requirement	Parameter monitored	Equipment Location	Monitoring Equipment	Equipment Shown on Appendix A Example Drawings
Monitoring ground surface settlements.	Level	Above and along the utility.	Ground movement marker for open ground or stud / nail for hard standing.	Stud – precise levelling of the ground. Drawings show a general arrangement of surface precise levelling points. This would need to be added to for any particular utility monitoring required.

5.2.6 Highways, Roads and Pavements

Where roads, highways and pavements are accessible safely, these will be monitored using levelling survey techniques, with studs or nails fixed in the surface. Where safe access is not possible, mini-prisms will be mounted in verges and central reservations, or the use of patch surveying techniques employed.

5.2.7 Railways (including Luas)

The monitoring of railway lines, including Luas, and associated infrastructure will be agreed with the railway operator on a case-by-case basis in accordance with their procedural approach. Infrastructure such as bridges and viaducts will be expected to be monitored as described by 5.2.4 above. Railway lines, due to access restrictions, will be monitored in real-time remotely using a combination of prisms to monitor x, y and z movements, tiltmeters and patch scanning.

5.2.8 Airport Infrastructure

The monitoring of all airport infrastructure will be subject to detailed discussions and will be agreed with the airport operator to suit operational requirements. Airport buildings and infrastructure will be monitored in a similar manner to that described above for buildings, bridges and viaducts, and railway lines. The airport is recognised as having particular security requirements, and therefore the emphasis will be on a monitoring system that is designed to minimise required access by using instrumentation that enables remote real-time monitoring.

5.2.9 Protection Measures

While there are no ground movement protection measures proposed at this time, although noting potential provision has been made for the Carroll's Building at Charlemont, the movement response of the ground and any structures in relation to the protection measure would be monitored to ensure they are behaving in accordance with the expected performance of the protection measure, and should they not be, provide sufficient warning in advance so corrective actions can be taken.

5.2.10 Internal Monitoring

As a result of stakeholder and community engagement, or the findings from inspections and surveys it may become apparent that selected internal monitoring of buildings and infrastructure is required. This may be because of the presence of specialist equipment, internal structures, or finishes that are sensitive to movement. Monitoring systems that could potentially be used for monitor internal movement include precise levelling, tiltmeters and crack meters.

5.3 Frequency of Monitoring Readings

The typical frequency of monitoring readings in normal circumstances is given in Table 5-5. As previously noted there will be exceptions such as railway and airport infrastructure where it will be necessary to employ real-time monitoring to assure the safe operation of infrastructure at all times.

Table 5-5 - Required Frequency of Monitoring Readings

Monitoring Equipment	Frequency of monitoring > 1 month before construction starts	Frequency of monitoring < 1 month before construction starts	Maximum frequency of monitoring – construction affecting	Frequency of monitoring – Post Construction
Optical monitoring system.	Monthly	Weekly	Hourly	Monthly
Building settlement markers and ground movement markers.	Monthly	Weekly	Daily or several times per day	Monthly
Inclinometers	Monthly	Weekly	Hourly	Monthly
Piezometers	Monthly	Weekly	Daily or several times per day	Monthly
Extensometers	Monthly	Weekly	Daily or several times per day	Monthly
Tiltmeters or crack meters if installed.	Monthly	Weekly	Daily or several times per day	Monthly

5.4 Monitoring Data and Information Management

All monitoring will be undertaken by the Contractor in collaboration with the Independent Monitoring Engineer and stored in a central data storage system that can also allow controlled read only access to third parties to view selected data if deemed appropriate. This type of access would not be suitable for a homeowner where instead this data will be assessed by a competent engineer and discussed in a review group as part of ongoing consultation with the community during periods of the works when settlement is occurring.

The Contractor will be responsible for the data management, storage, and distribution of information and dashboards to the Independent Monitoring Engineer (IME), TII and appropriate stakeholders. The management system will be capable of displaying information in a useable format, as 2D or 3D plots, as graphical information related to time and space, and will send alerts to the IME, Contractor, Designer, TII and appropriate stakeholders when there are breaches of trigger levels (see section 5.5) The system will also be capable of determining when activities may be trending towards a breach of a trigger level ahead of completion of the construction activity causing the ground movement.

The works will be monitored continuously using a combination of automatic and manual monitoring. Automated monitoring readings will be continuously recorded with date and time stamp and transferred at the frequency of each instruments monitoring cycle. The readings will then be automatically processed for viewing and assessment by the monitoring and construction team. The readings will also be linked to automatic triggers as set out by section 5.5.

There will also be manual monitoring to supplement and compliment the automated systems. Manual monitoring is deployed where continuous monitoring is not necessary using instruments such as precise levels and total stations. The data is initially stored within the reading instrument and is processed and assessed at each shift review group informing the next shift's work.

5.5 Action and Contingency Plans

5.5.1 Monitoring Action Plans (MAP)

Monitoring Action Plans (MAP) will be developed detailing responses to breaches of trigger levels for each type of asset and/or specific assets as appropriate. Action plans will comply with the procedures established by asset owners where such procedures exist.

Typically, MAP's will comprise a short document containing:

1. An outline diagram of the monitoring set under consideration;
2. A table showing trigger levels and associated actions on trigger exceedance; and
3. Names, email and phone numbers of key contacts.

5.5.2 Trigger Levels

The contract specification for ground movement instrumentation and monitoring will set out the requirements for trigger conditions to be applied and will most likely comprise of a traffic light system similar to that shown in Figure 5-1 below:

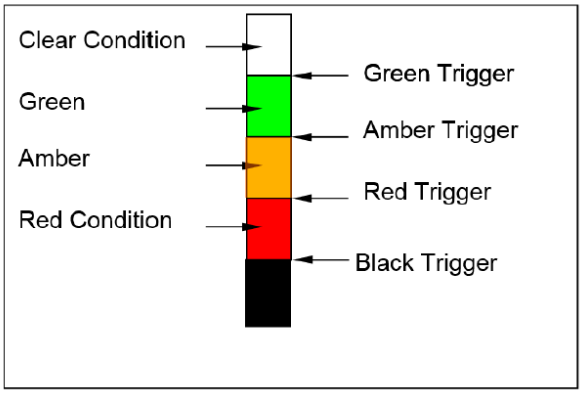


Figure 5-1 Monitoring Conditions and Trigger Levels

All monitoring points will be surveyed for installed position and the appropriate trigger values assigned following reference to the appropriate design or assessment movements model. Indicative amber trigger values will be set at around 80% of the design or assessment output values, with the red trigger values set at 80% of asset permissible limiting stress. Black trigger values will be set at the time of any Emergency Engineering Review taking into account safety and serviceability of the particular asset(s) affected and may involve the cessation of all relevant site work.

5.6 Typical Monitoring Arrangements

5.6.1 St Stephen's Green Exemplar Design

The purpose of this section is to illustrate what could be required in terms of ground movement instrumentation and monitoring, by taking St Stephen's Green as an exemplar area, to facilitate an understanding of the range and scale of monitoring that will be employed for MetroLink. It is probable that the contractor-designed and installed ground movement monitoring system will vary from the exemplar reflecting that the MetroLink design will have undergone further development and analysis, as well as being influenced by contractor preference, but the principles and performance outcomes will remain the same.

Drawings showing a possible configuration of ground movement instrumentation and monitoring in the St Stephen's Green area are included as Appendix A. These drawings have been developed based on the discussion below that consider in four discrete elements:

1. Building monitoring requirements in response to station excavation.
2. Building monitoring requirements in response to tunnel excavation.
3. Station excavation construction monitoring.
4. Tunnel excavation construction monitoring.

While baseline movement monitoring has not been specifically shown on the drawings, it may simply comprise of the full monitoring system as shown, installed in advance of construction, to determine seasonal movements. Alternatively, it may be a subset of the full monitoring regime, for instance just precise levelling studs. A more innovative solution to determine the movement baseline could be the use of satellite InSar, from which historic ground movements at, for example weekly intervals, could be measured. For this paper it is assumed that the baseline monitoring is a sub-set of the construction monitoring scheme, which will amount to some 10% of the precise levelling studs, prisms and piezometers used for the construction phase monitoring, focussed on areas, infrastructure and buildings known to be particularly sensitive, or subject to known ground movements or tidal fluctuations.

While at this time no internal movement monitoring of property is proposed, it is likely this will be required for selected properties as a result of the findings from inspections and surveys, and future stakeholder and community engagement, where it may become apparent that selected internal monitoring of buildings and infrastructure is required for reasons such as the presence of specialist equipment, or internal structures or finishes that are sensitive to movement. In the event this is found to be the case, movement monitoring systems that could potentially be used include precise levelling, tiltmeters and crack meters.

Finally, it is important to note that this exemplar is based on the findings of the Preliminary Design ground movement response assessment and therefore it is possible that as the design is further developed and refined, the predicted ground movements may reduce and thus also influence the design of the instrumentation and monitoring system.

5.6.2 St Stephen's Green Station Excavation - Building Monitoring

Buildings B1 to B10 (see Figure 5-2) are affected by station excavation and as shown by Table 5-6 (extract from the MetroLink Damage Assessment Report ML1-JAI-GEO-ROUT_XX-RP-Y-00024) but noting the impact of station excavation on these buildings is modest. Buildings B3 to B7 experience nearly 15mm settlement of the front façade reducing to the 1mm contour some 30m behind the façade, with only one property, B6, categorised with 'slight' damage, the rest being classified as 'very slight' or 'negligible'. However, six of these buildings are categorised as "special" in the building damage assessment, and since they are mostly interconnected, it is proposed to monitor all these buildings B1-10.

It is proposed to fix prisms as part of a Robotic Total Station (RTS) system at three levels vertically along the building façade as highlighted in yellow on Figure 5-2, and install precise levelling points along the stone dwarf wall at the frontages of these properties. Figure 5-3 shows the proposed locations of prisms and precise level points, shown as red dots and yellow dots respectively. Generally, the spacing of the precise levelling points would be at 5m and at corners/changes of direction. Precise levelling points can also be installed behind the façade where access is obtainable through alleyways and in courtyards.

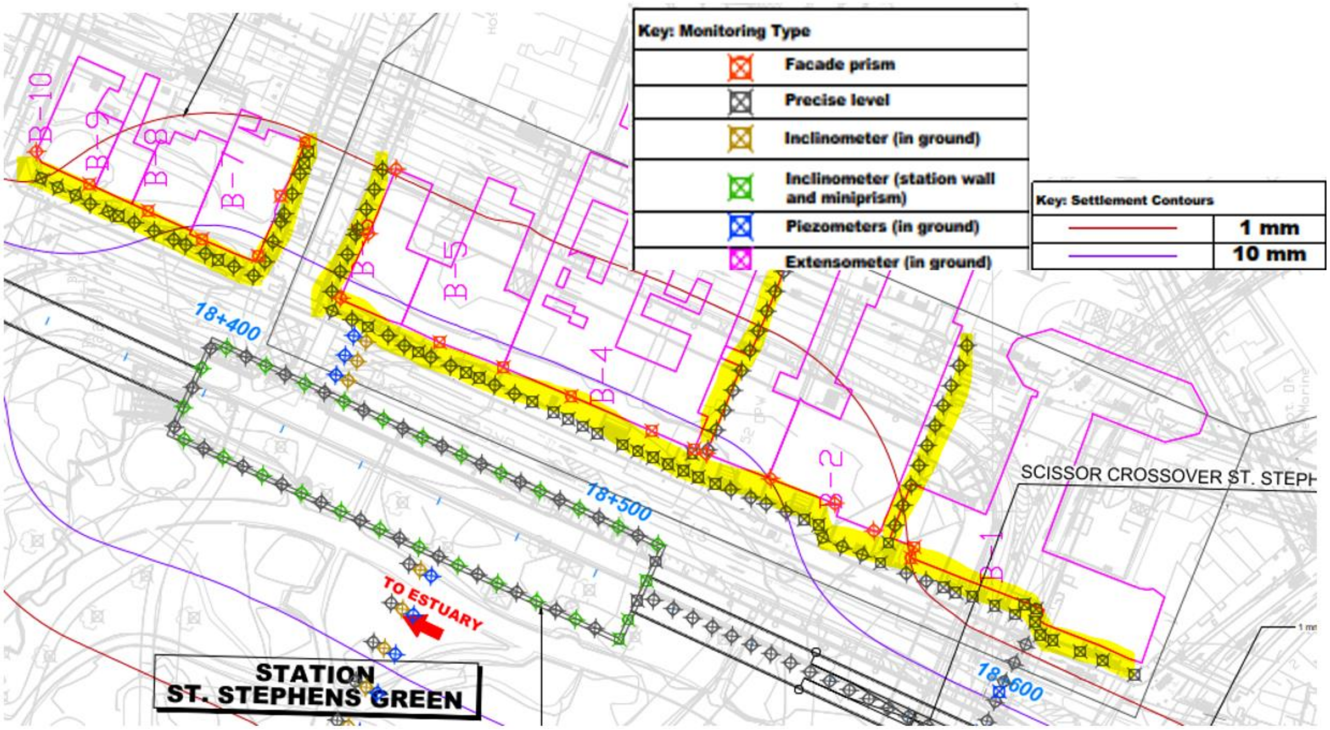


Figure 5-2 St Stephen's Green – Buildings Affected by Station Excavation (Including Building Façades requiring fixed monitoring, highlighted in yellow)

Table 5-6 – St Stephen's Green Station Excavation: Building Details and Predicted Impact

Ref	Chainage	Description	Height (m)	Number of Floors	Length (m)	Depth of basement (m)	Initial Phase 2a Assessment Damage Category	Refined Phase 2a Assessment Damage Category	RPS, NIAH, RMP or other heritage (Y/N/unknown)	Continue to next assessment phase? (Y/N)	Comments
B-1	18620	Permanent TSB Head Office	20.0	4	64.9	-2.5	N/A	N/A	Y	N	Outside 1mm contour
B-2	18580	Loreto College	20.0	4	88.9	-3.0	0 (Negligible)	0 (Negligible)	Y	Y	Special building
B-3	18500	OPW	25.0	6	111.3	-3.0	0 (Negligible)	0 (Negligible)	Y	Y	Special building
B-4	18520	Department of Justice and Equality	20.0	3	60.7	-2.5	0 (Negligible)	0 (Negligible)	Y	Y	Special building
B-5	18480	Australian Embassy	20.0	5	39.8	-2.5	0 (Negligible)	0 (Negligible)	N	N	Damage category 2 or below
B-6	18460	Housing Finance Agency	20.0	5	32.9	0.0	2 (Slight)	2 (Slight)	N	N	Damage category 2 or below
B-7	18420	Ivor Fitzpatrick and Co	20.0	5	31.6	-2.5	0 (Negligible)	0 (Negligible)	N	N	Damage category 2 or below
B-8	18400	Boston College - St. Stephen's Green	13.0	4	22.2	-2.5	0 (Negligible)	0 (Negligible)	Y	Y	Special building
B-9	18380	Forty-One Restaurant	16.0	3	29.0	-2.5	0 (Negligible)	0 (Negligible)	Y	Y	Special building
B-10	18380	Bank of Ireland	15.0	3	26.1	-3.0	0 (Negligible)	0 (Negligible)	Y	Y	Special building

Figure 5-3 Proposed Monitoring of Buildings on the East Side of St Stephen's Green

5.6.3 St Stephen's Green, Tunnel Excavation South of St Stephen's Green - Building Monitoring

Buildings AB37, B52, B53, B55, B238, AB38, AB39, B147, and B148 are affected by tunnel construction (see Figure 5-4 and Table 5-7). Figure 5-8 shows the proposed monitoring arrangement for tunnel excavation south of St Stephen's Green. No fixed monitoring is proposed for AB37, but consideration should be given to carrying out target-less scanning/patch survey monitoring during and after the TBM passage as an additional precaution. Precise levelling points and a limited number of facade prisms are proposed to be installed around the east side of B52, the National Concert Hall, designated as a "special" building, although settlements are negligible, and no significant impact is expected.

For building B53, ground settlement is potentially up to 40mm on the south-west corner; since the impact is 'very slight' and the building is not categorised as "special" this would not normally qualify for fixed monitoring, but again it may be prudent to undertake target-less scanning/patch survey monitoring before, during and after the passage of the TBM as an additional precaution. B238, the Arthur Cox building is a "special" building, subject to some 40mm of settlement, and therefore it is proposed to install prisms on all faces of this building as shown by Figure 5.5.

Buildings AB38 and B55 (listed as "special" from the Building Damage Assessment) are traditional brickwork construction and both are subject to approximately 25mm of settlement at the back of the building, and 5-10mm at the front. For this structure it is proposed to install three rows of 3 prisms to the front and back of the building (18 prisms in total), to be surveyed at periods before, during and after the passage of the TBM. For the building which has replaced AB39 and B147 since MetroLink building surveys were undertaken, a further assessment of the form of structure and its susceptibility to settlement would need to be carried out. For B148, although it is a "special" building, it is barely affected by any movement and therefore any settlement is likely to be too small to reasonably measure, so no fixed monitoring is proposed for this building.

Figure 5-4 St Stephen's Green – Plan of Buildings along Earlsfort Terrace Affected by Tunnel Excavation (including façades requiring fixed monitoring, highlighted in yellow)

Table 5-7 – Running Tunnel Excavation South of St. Stephen's Green: Extracted Building Details and Predicted Impact

Ref	Chainage	Description	Height (m)	Number of Floors	Length (m)	Depth of basement (m)	Initial Phase 2a Assessment Damage Category	Refined Phase 2a Assessment Damage Category	RPS, NIAH, RMP or other heritage (Y/N/unknown)	Continue to next assessment phase? (Y/N)	Comments
B-52	18840	National Concert Hall	10.5	3	117.3	0.0	0 (Negligible)	0 (Negligible)	Y	Y	Special building
B-53	18920	Public	14.0	4	3.0	0.0	2 (Slight)	1 (Very Slight)	N	N	Damage category 2 or below
B-55	18980	Residential	19.0	4	14.5	-2.0	1 (Very Slight)	0 (Negligible)	Y	Y	Special building
B-147	19020	Davitt House	12.0	4	26.0	-2.5	2 (Slight)	2 (Slight)	N	N	Damage category 2 or below
B-148	19100	Residential	11.8	3	37.8	0.0	0 (Negligible)	0 (Negligible)	Y	Y	Special building
B-238	18980	Arthur Cox Building	40.0	7	17.8	-8.1	2 (Slight)	2 (Slight)	N	Y	Case B (refer to section 4.1)

AB-37	B-52a	18700	Commercial	15.0	5	24.6	0 (Negligible)	N	N	Damage category 2 or below
AB-38	B-55a	18960	Commercial	12.0	4	18.5	0 (Negligible)	N	N	Damage category 2 or below
AB-39	B-147a	19000	Commercial	12.0	4	46.5	1 (Very Slight)	N	N	Damage category 2 or below

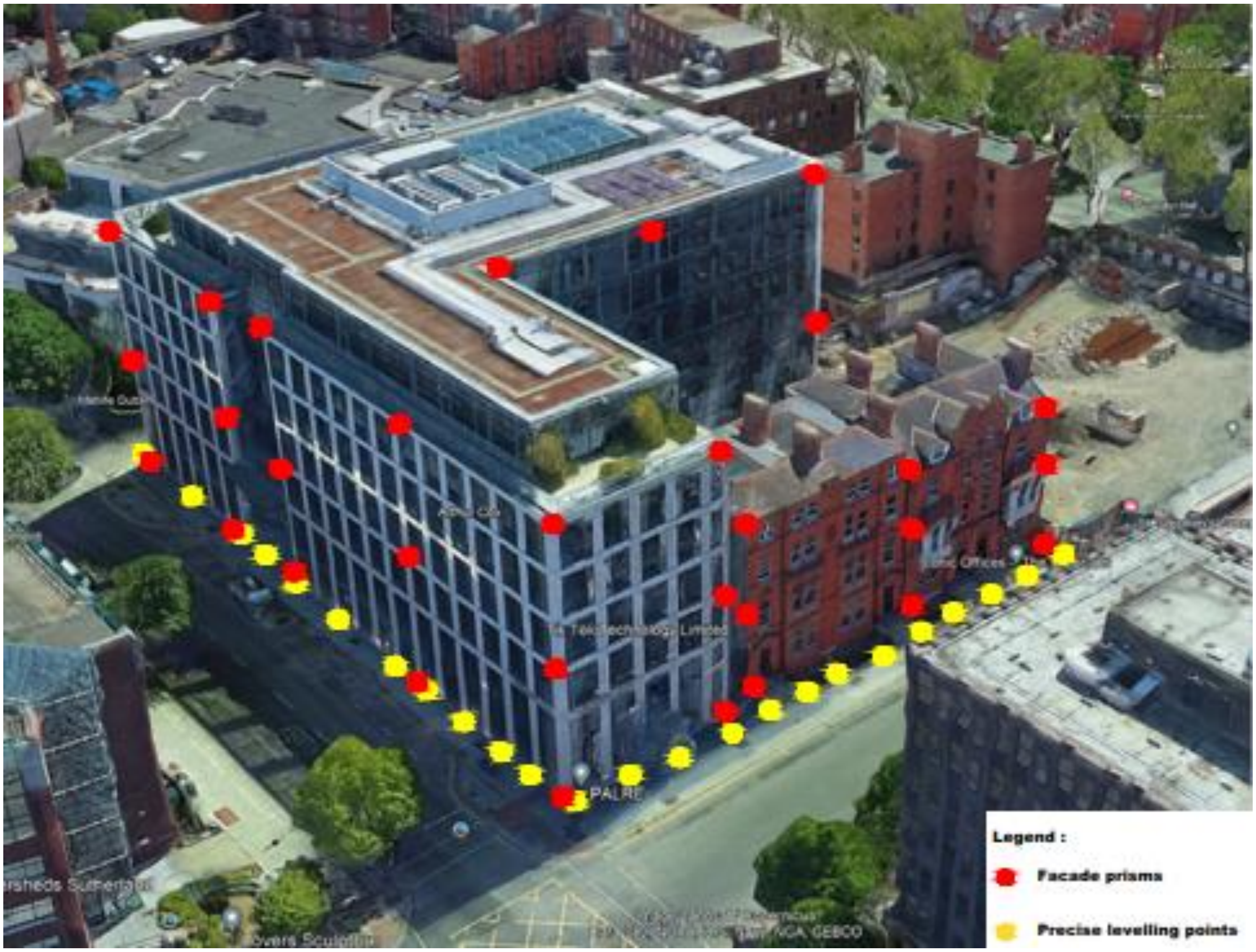


Figure 5-5 Proposed Monitoring of Buildings along Earlsfort Terrace

5.6.4 St Stephen's Green Station Excavation - Construction Monitoring

St Stephen's Station box excavation is approximately 30m deep, excavated through soils into limestone. Figure 5-6 illustrates the anticipated construction monitoring to be undertaken during excavation of the station box.

Based on the preliminary design, diaphragm walls will be constructed to depth. The Contractor will need to understand the performance of this walling by measuring its shape, or tilt, during excavation, and the level of at least the top of the wall, but possibly also at lower wall levels. It is therefore anticipated that inclinometers would be installed within the wall at 10m intervals, and that measurements of level are made at 5m intervals along the top of the wall, including mini-prisms at the top of the inclinometers to measure the x, y, z position at the top of each inclinometer.

The Contractor will also need to understand the movement of the ground adjacent to the walling and any change in ground water levels. This will be accomplished by precise levelling points at intervals in transverse arrays perpendicular to the wall, and transverse rows of inclinometers and piezometers also perpendicular to the station excavation.

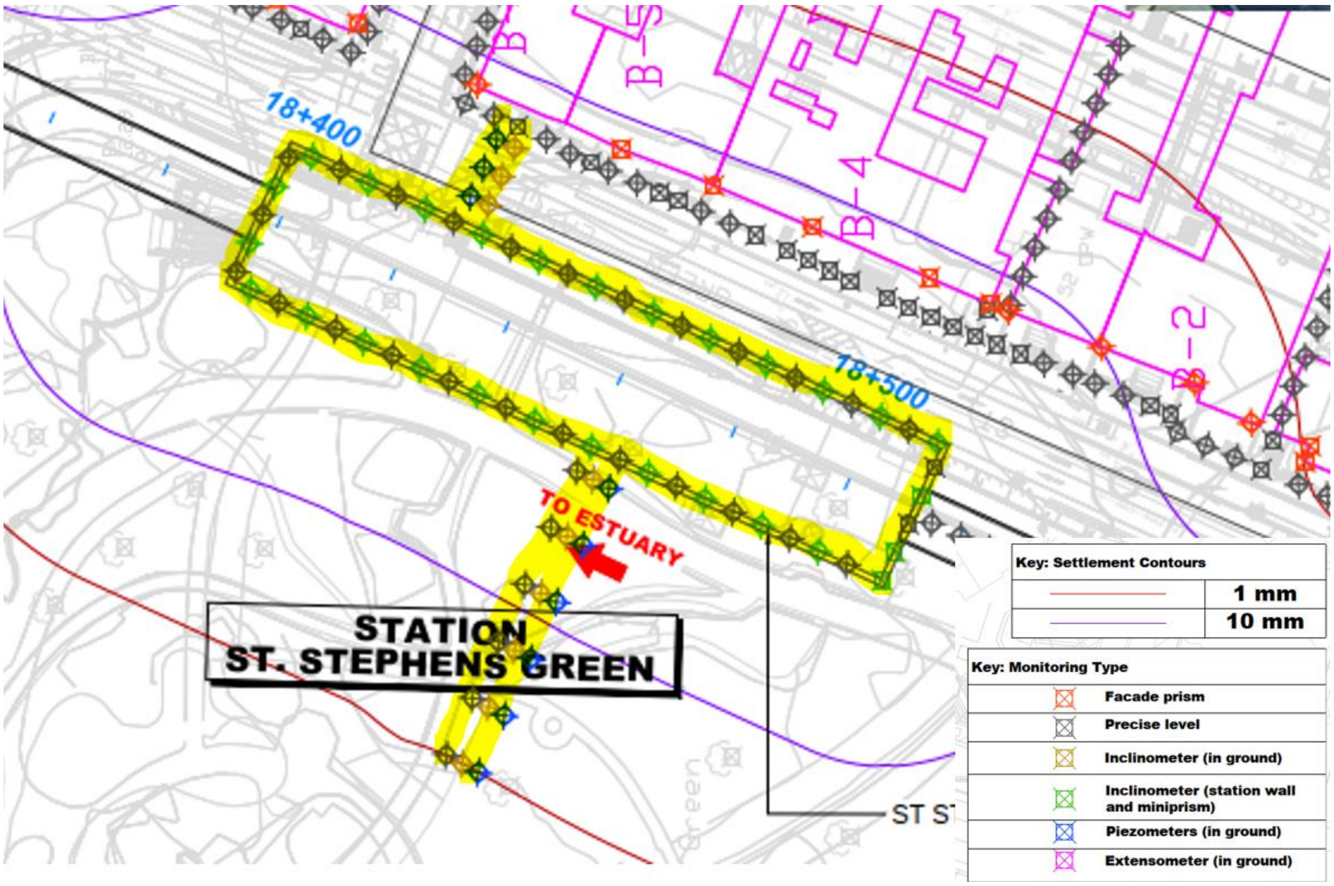


Figure 5-6 Station Excavation Proposed Construction Monitoring (highlighted)

5.6.5 St Stephen's Green, Tunnel South of St Stephen's Green - Construction Monitoring

Monitoring of the ground settlement trough and the subsoil over and around the tunnel excavation yields valuable information on the ground and performance of the Tunnel Boring Machine (TBM), as well as informing improvements to the tunnelling process. The proposed monitoring shown by Figure 5-7 is an example of what the Contractor might employ but noting the actual location of such monitoring arrays will depend on actual construction conditions, the precise start/end point of tunnel drives, and any requirements to evidence and thus demonstrate TBM performance to the community and stakeholders potentially impacted by tunnel construction.

Construction monitoring for the tunnel will comprise precise levelling points located along the tunnel centreline and at cross sections perpendicular to the tunnel centreline. An opportunity for tunnel settlement monitoring is south of the station excavation, as shown in Figure 5-7. Monitoring cross sections are also proposed along crossing roads i.e. Hatch Street and Adelaide Road, and a longitudinal settlement profile monitoring array is proposed along Earlsfort Terrace, as shown in Figure 5-8. Cross section precise levelling pins can be installed in one or both footpaths that can also serve as monitoring for utilities running in the footpaths. Piezometers, inclinometers and extensometers can also be installed at these road locations, if needed, and as shown by Figures 5-7 and 5-8, and the drawings in Appendix A.

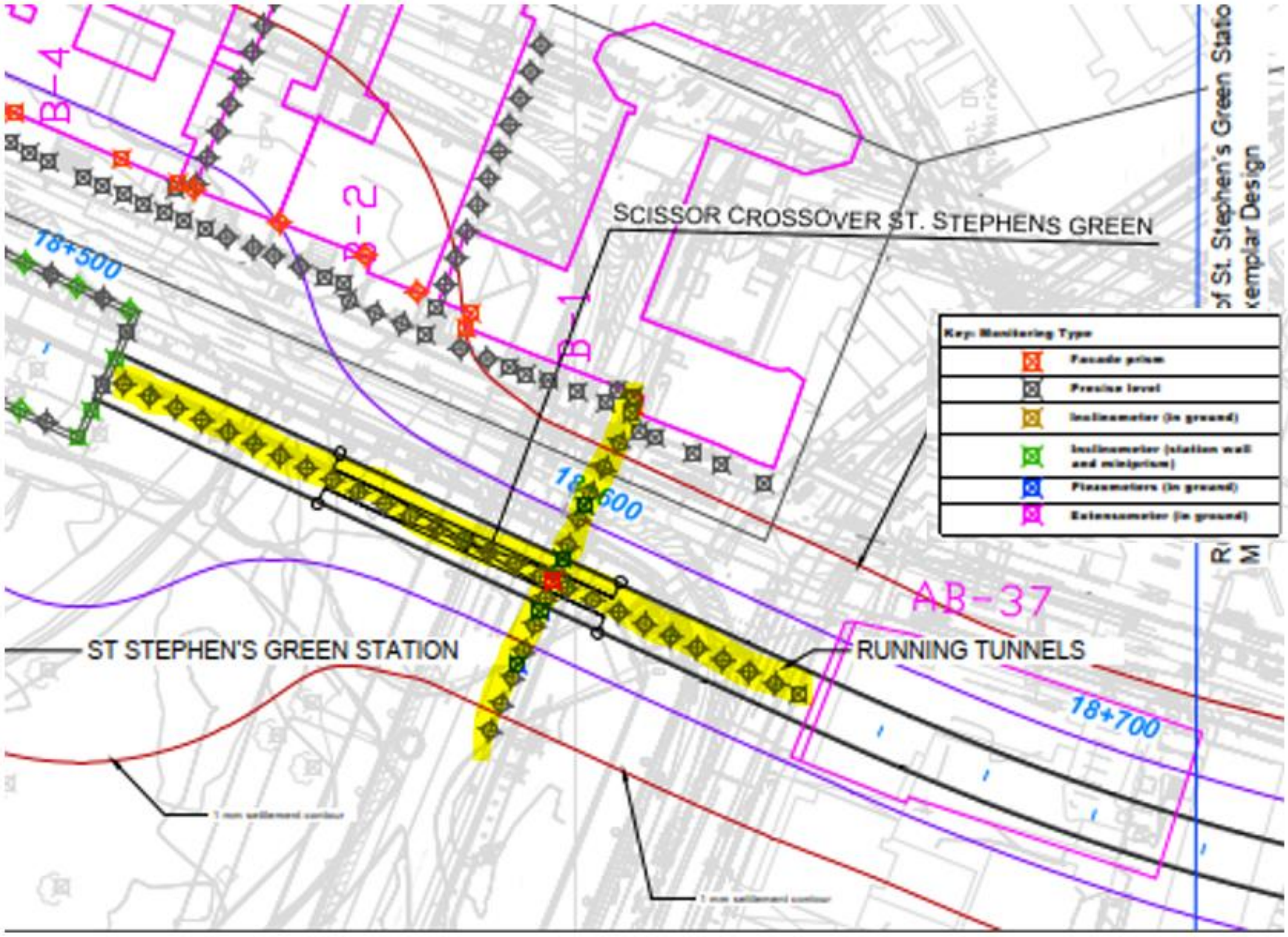


Figure 5-7 St Stephen’s Green Tunnel Construction Monitoring – Precise Levelling Points

Figure 5-8 St Stephen’s Green Tunnel Construction Monitoring – Precise Levelling Points in Roads

6. Surveys to Inform the Instrumentation and Monitoring Design

Inspections and surveys, including condition surveys, will provide important information that will inform the building and infrastructure ground movement response assessment, and the corresponding instrumentation and monitoring design.

6.1.1 Inspections and Surveys

All buildings and infrastructure that are identified as lying within the predicted ground movement zone of influence (ZOI), noting the extent of the ZOI is a conservative estimate, will as a minimum be inspected externally (and internally where deemed appropriate), assuming permission is granted to do so, to ensure that any particular characteristics are identified. The information collected by these inspections will be fed back into the building and infrastructure ground movement response assessment and consideration given to whether further surveys and structural assessment should be undertaken to investigate particular characteristics. These will include by way of example consideration of other factors such as infrastructure criticality, historical or cultural significance, condition, structural configuration, features or structures particularly sensitive to movement, temporary works being undertaken by the property owner such as internal propping, and movement tolerances taking account of any previous movement experienced that will mean the tolerance to movement is reduced.

These follow up surveys will require specialists such as structural engineers, engineers with particular expertise relevant to the building or infrastructure being surveyed, surveyors for establishing the existing position of infrastructure such as railway lines and bridges to understand movement experienced to date, and conservation specialists by way of example. Again, these findings will be taken account of by the ground movement building and infrastructure response assessment that will subsequently inform the ground movement monitoring design.

Given the quantity of inspections and surveys to be undertaken, the logistics of; planning and resourcing surveys and managing access and permissions; cataloging, storing and feeding back this information into the design; and adjusting the ground movement impact assessment and design of the monitoring system as necessary means this process will need to start in good time before commencement of the works. It will therefore be vital to develop a programme for delivering these inspections and surveys so this information is available in sufficient time to inform the design.

Permissions to undertake the inspections and surveys will need to be sought, and the precursor to this will be the necessary engagement with building and infrastructure owners to inform and gain these permissions. This will also provide a further opportunity to understand from the property owner any historical background or points of note regards the property concerned.

There will be some inspections and surveys that may be best carried out or need to be carried out by the property owner, for example particular internal sewer surveys. It would also be expected there will be in existence previous survey information for some infrastructure such as railways lines, airport hard standings, sewers etc. and that this will need to be requested from infrastructure owners.

These inspections and surveys will also provide a further opportunity to draw upon local community and infrastructure owner knowledge, and obtain any historical records such as drawings, technical papers and records of construction.

6.1.2 Condition Surveys

Condition surveys will be undertaken by the Contractor in advance of the works commencing, subject to the permission of the property owner, to enable determination of whether there has been any deterioration of the surveyed property over the duration of the MetroLink works and whether this may be attributable to MetroLink. These condition surveys, in terms of assessing whether Metrolink generated movements have impacted the property concerned, have a direct link to the movement monitoring undertaken through all three phases (Baseline, Construction, and Close-Out) by assisting with ascertaining the cause of any property deterioration identified. The completion of the Close-Out monitoring is a key milestone for drawing the duration of the condition surveys to a close.

Condition surveys undertaken will take the form of:

- Pre-works Condition Surveys;
- Interim-works Condition Surveys (if required for example due to; a change in condition, unexpected movement, or at request of property owner due to concerns);
- Interim-works Condition Surveys (Post repair works and if required); and
- Post-works Condition Surveys.

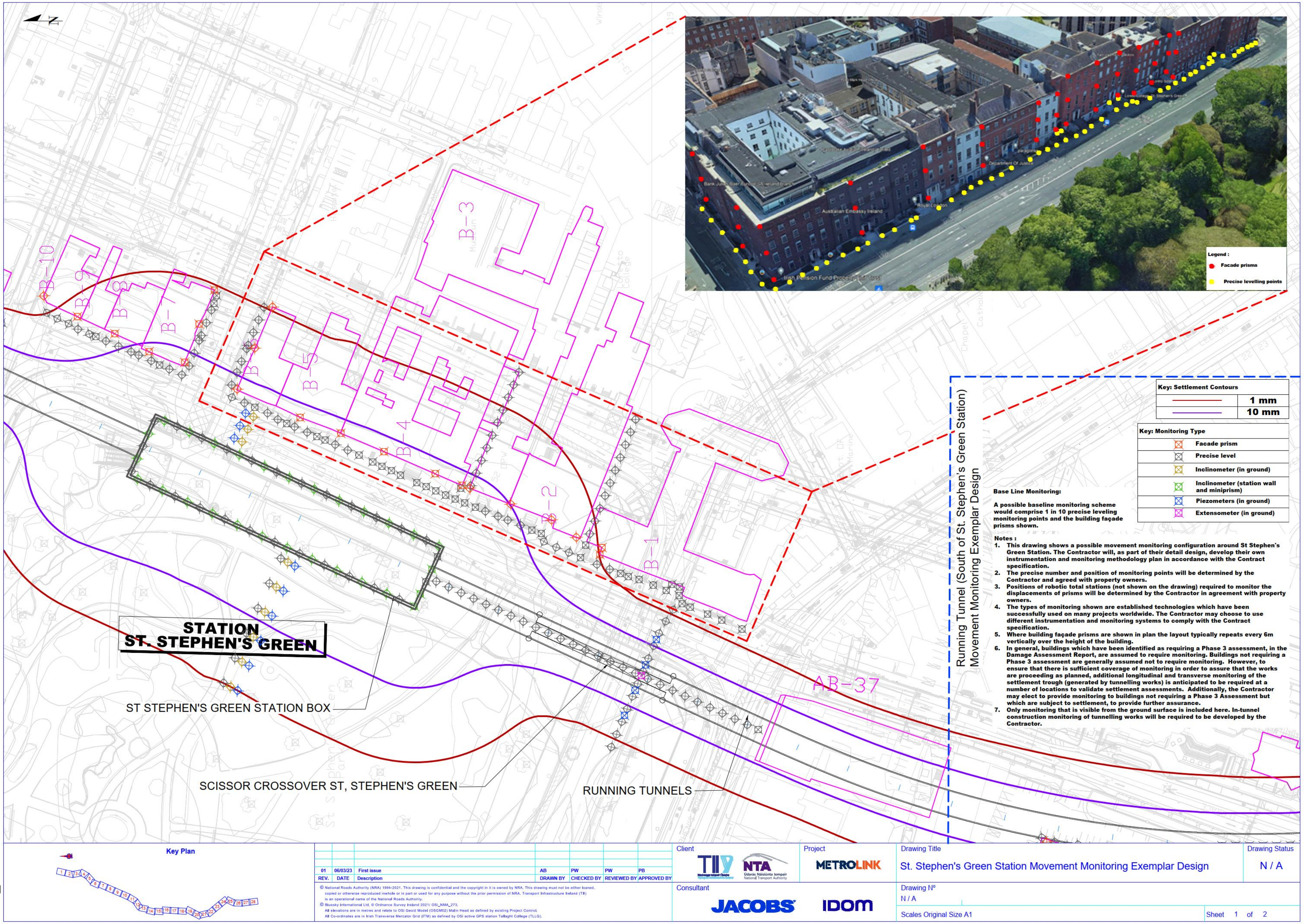
The extent of property that will be subject to a condition survey will depend on a variety of factors, including:

- predicted movements and possible property impacts;
- sensitivity of the property to movement, which will also need to take account of historical and cultural significance, and infrastructure criticality;
- the desire of property owners to have a condition survey;
- the Contractor's preference as to what extent they want to ensure property condition is understood before commencement of the works;
- TII works specification; and
- Conditions applied to the granted Railway Order

In a similar manner to the inspections and surveys, the information recorded by the condition surveys will be fed back into the ground movement assessment response and the subsequent movement monitoring design. Given the synergy between condition surveys and the aforementioned inspections and surveys, there is an opportunity for some rationalisation of surveys undertaken whilst still being able to collect the necessary information. It would also be helpful to do this to avoid unnecessary criticism from property owners that surveys and inspections come across as uncoordinated and requiring what appears to the property owner as unnecessary repeat visits to the property that could have been rationalised.

Finally, it is of note that there will be a voluntary Property Owners Protection Scheme (POPS) in place that will afford residential property owners the opportunity where they lie within the zone defined by this scheme to register their property for an initial condition survey (before commencement of works that could impact their property), and a final condition survey on cessation of works. The timing of this final condition survey will be determined by the Close-Out phase of the movement monitoring and confirmed cessation of movements that could impact the property. The interaction of the POPS with contractor delivered condition surveys will require consideration from a contractual, community engagement and consistency perspective should contractor and POPs condition surveys be undertaken separately.

Appendix A: Exemplar Movement Monitoring Design


B-10
B-9
B-8
B-7
B-6
B-5
B-4
B-3
B-2
B-1
AB-37
Legend :
Facade prisms
Precise levelling points
STATION
ST. STEPHEN'S GREEN
ST STEPHEN'S GREEN STATION BOX
SCISSOR CROSSOVER ST, STEPHEN'S GREEN
RUNNING TUNNELS
Running Tunnel (South of St. Stephen's Green Station)
Movement Monitoring Exemplar Design
Key: Settlement Contours
1 mm
10 mm
Key: Monitoring Type
Facade prism
Precise level
Inclinometer (in ground)
Inclinometer (station wall and miniprism)
Piezometers (in ground)
Extensometer (in ground)
Base Line Monitoring:
A possible baseline monitoring scheme would comprise 1 in 10 precise leveling monitoring points and the building façade prisms shown.
Notes :
1. This drawing shows a possible movement monitoring configuration around St Stephen's Green Station. The Contractor will, as part of their detail design, develop their own instrumentation and monitoring methodology plan in accordance with the Contract specification.
2. The precise number and position of monitoring points will be determined by the Contractor and agreed with property owners.
3. Positions of robotic total stations (not shown on the drawing) required to monitor the displacements of prisms will be determined by the Contractor in agreement with property owners.
4. The types of monitoring shown are established technologies which have been successfully used on many projects worldwide. The Contractor may choose to use different instrumentation and monitoring systems to comply with the Contract specification.
5. Where building façade prisms are shown in plan the layout typically repeats every 6m vertically over the height of the building.
6. In general, buildings which have been identified as requiring a Phase 3 assessment, in the Damage Assessment Report, are assumed to require monitoring. Buildings not requiring a Phase 3 assessment are generally assumed not to require monitoring. However, to ensure that there is sufficient coverage of monitoring in order to assure that the works are proceeding as planned, additional longitudinal and transverse monitoring of the settlement trough (generated by tunnelling works) is anticipated to be required at a number of locations to validate settlement assessments. Additionally, the Contractor may elect to provide monitoring to buildings not requiring a Phase 3 Assessment but which are subject to settlement, to provide further assurance.
7. Only monitoring that is visible from the ground surface is included here. In-tunnel construction monitoring of tunnelling works will be required to be developed by the Contractor.
Key Plan
01 | 06/03/23 | First issue | AB | PW | PW | PB
REV. | DATE | Description | DRAWN BY | CHECKED BY | REVIEWED BY | APPROVED BY
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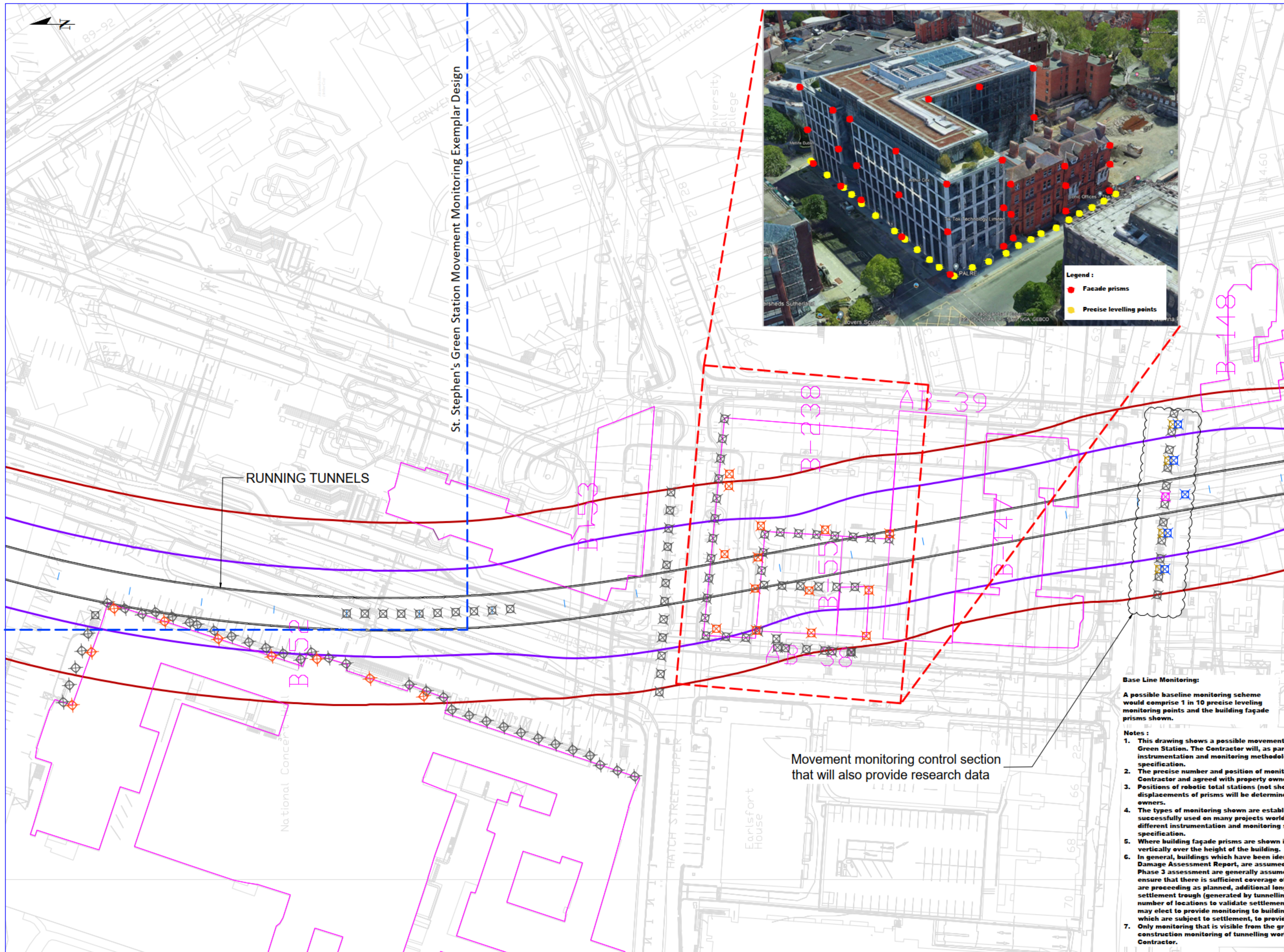
All elevations are in metres and relate to OSi Geoid Model (OSGM02) Malin Head as defined by existing Project Control.
All Co-ordinates are in Irish Transverse Mercator Grid (ITM) as defined by OSi active GPS station Tallaght College (TLLG).
Client
Project
Drawing Title
St. Stephen's Green Station Movement Monitoring Exemplar Design
Drawing Status
N / A
Consultant
Drawing Nº
N / A
Scales Original Size A1
Sheet 1 of 2



Key: Settlement Contours

(red line)	1 mm
(purple line)	10 mm

Key: Monitoring Type

(orange symbol)	Facade prism
(grey symbol)	Precise level
(yellow symbol)	Inclinometer (in ground)
(blue symbol)	Piezometers (in ground)
(magenta symbol)	Extensometer (in ground)

Base Line Monitoring:

A possible baseline monitoring scheme would comprise 1 in 10 precise leveling monitoring points and the building façade prisms shown.

Notes :

1. This drawing shows a possible movement monitoring configuration south of St Stephen's Green Station. The Contractor will, as part of their detail design, develop their own instrumentation and monitoring methodology plan in accordance with the Contract specification.
2. The precise number and position of monitoring points will be determined by the Contractor and agreed with property owners.
3. Positions of robotic total stations (not shown on the drawing) required to monitor the displacements of prisms will be determined by the Contractor in agreement with property owners.
4. The types of monitoring shown are established technologies which have been successfully used on many projects worldwide. The Contractor may choose to use different instrumentation and monitoring systems to comply with the Contract specification.
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7. Only monitoring that is visible from the ground surface is included here. In-tunnel construction monitoring of tunnelling works will be required to be developed by the Contractor.

Key Plan

REV.	DATE	Description	DRAWN BY	CHECKED BY	REVIEWED BY	APPROVED BY
01	06/03/23	First issue	AB	PW	PW	PB

All elevations are in metres and relate to OSi Geoid Model (OSGM02) Malin Head as defined by existing Project Control.
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Client: TII, NTA

Project: METROLINK

Consultant: JACOBS, IDOM

Drawing Title: Running Tunnel (South of St. Stephen's Green Station) Movement Monitoring Exemplar Design

Drawing Status: N / A

Drawing Nº: N / A

Scales Original Size A1

Sheet 2 of 2