Railway Procurement Agency

METRO NORTH

ORAL HEARING

PROOF OF EVIDENCE

Rupert Taylor

Vibration and Groudborne Noise

Wednesday 8th April 2009

Metro North Oral Hearing

Proof of Evidence

Groundborne Noise & Vibration

Rupert Thornely-Taylor

1.0 NAME, QUALIFICATIONS AND ROLE IN PROJECT

1.1 My name is Rupert Maurice Thornely-Taylor.

1.2 I am a Fellow of, and was a founder member of, the Institute of Acoustics, a Member of the Institute of Noise Control Engineering of the USA and a Member of the International Institute of Acoustics and Vibration. I have specialised exclusively in the subjects of noise, vibration and acoustics for more than 44 years. I have been an independent consultant in these subjects for the past forty years, and head the practice known as Rupert Taylor F.I.O.A.

1.3 I am President of the Association of Noise Consultants and a Director of the International Institute of Acoustics and Vibration. I was for ten years a member of the British Government's Noise Advisory Council chaired by the Secretary of State for the Environment, and was chairman and deputy chairman of two of its working groups; I was a member of the Scott Committee, which drafted the basis of the noise section of the UK Control of Pollution Act 1974. I am the author of the Pelican book NOISE, and editor or co-author of many other books.

1.4 My role on the Metro North project has been to assess the potential vibration and groundborne noise impacts from the construction and operation of the scheme and to advise the RPA on appropriate mitigation measures.

2.0 EXPERIENCE

2.1 I have specialised in noise and vibration from railways since the early 1970s.I was noise and vibration consultant to the Docklands Light Railway (DLR) in London, and have been involved in its City, Beckton, Lewisham, City Airport, Woolwich Arsenal and Dagenham Dock Extension projects. I was expert witness in both Houses of Parliament during the committee stages of all the DLR and Croydon Tramlink Bills. I was noise and vibration consultant to (and expert witness in Parliament for) the original Crossrail and Jubilee Line Extension Projects in the UK, and was expert witness in the House of Commons committee on the Channel Tunnel Rail Link Bill on behalf of Union Railways. I was expert witness for Network Rail in the Thameslink 2000 public inquiries, and in both the House of Commons and House of Lords Select Committees on the Crossrail Bill in the UK.

2.2 I was engaged in the design of the Kowloon-Canton Railway West Rail project in Hong Kong, the Citytunnel project in Malmö, Sweden, and Västlänken in Gothenburg. I was part of the Independent Verifier team for Parramatta Rail Link in Sydney, Australia. I am consultant in the construction of Edinburgh Tram, and have been engaged in vibration studies on Nottingham Express Transit in the UK.

2.3 A substantial part of my experience relating to noise and vibration from railways has been in the field of the acoustical design of rolling stock. I carried out a noise study of the TGV as part of the acoustical design of the British Rail East Coast Main Line (Intercity 225) Mk IV Coaching Stock. I was noise consultant in the design of the GEC-Alstom (Metro-Cammell) Networker Class 465, and in other Electric Multiple Unit (EMU) designs such as the Class 323 built by Hunslet. I also was engaged in acoustical design work on Channel Tunnel Shuttle vehicles in 1987/88, and provided computer software to a French company involved in the design of those vehicles. In 2005, I completed a train noise levels study of vehicles built by Rotem of Korea for Delhi Metro Rail Corporation, India, and was involved in a survey of the interior noise levels of all the vehicle types owned by one of the Rolling Stock Companies (ROSCOs) in the UK.

2.4 I have extensive experience of construction vibration, and carried out construction noise studies of the Jubilee Line Extension, and have been expert witness on construction noise in inquiries into several major infrastructure developments.

2.5 My practice is currently under contract to the UK Department for Environment, Food and Rural Affairs (Defra) to investigate the effectiveness of the Environmental Impact Assessment (EIA) process in dealing with noise impacts.

2.6 I was largely responsible for the preparation of Chapter 5 in each of the seven books of Volume 2 of the EIS. I have been a subconsultant to ERM for the Metro North project for approximately three years and am a consultant to the RPA.

3.0 GENERAL INTRODUCTION

3.1. The scope of my evidence concerns the effects of groundborne noise and vibration from the construction and operation of Metro North. My evidence consists of the content of the EIS on groundborne noise and vibration together with matters which have arisen since the publication of the EIS.

3.2. The effect of vibration of elevated structures insofar as it affects structure-radiated airborne noise to the wayside environment is addressed in the noise evidence and is not covered here.

3.3. I will firstly describe the environment in which groundborne noise and vibration effects are received. Secondly I will explain the assumptions and methodology used in assessing the effect of the construction and operation of Metro North. Thirdly I will set out the criteria used for assessing the significance of effects. Fourthly I will describe the approach to mitigating significant effects and finally I will describe the results in terms of the residual significant effects.

4.0 RECEIVING ENVIRONMENT

Area MN101 Belinstown to Swords Stop

4.1 From Belinstown to the location for Estuary Stop the alignment is at grade so that groundborne noise and vibration would not normally require consideration except in buildings very close to the track. At Estuary the alignment then rises up onto an elevated section of track, descending to reach the next at grade stop, at Seatown from where it continues at grade until it descends to pass under the Malahide Roundabout. Baseline vibration monitoring at Seatown Road, Swords was in the very high category.

4.2 The depot is located just north of the terminus at Belinstown on an earthworks platform.

4.3 The principal receptor sensitive to vibration in this area is Siemens Healthcare Diagnostics Manufacturing Ltd in Chapel Lane, Swords, a manufacturer of large hospital and laboratory based immunology and haematology diagnostic instrumentation which is vibration sensitive.

4.4 The central section of the Lissenhall Bridge is some 500 years old. The arches are lined with original lime plaster.

4.5 The Emmaus Retreat and Conference Centre is sensitive to noise and vibration.

Area MN102 Swords Stop to Dublin Airport north portal

4.6 From south of the Swords Stop, the alignment rises up onto an elevated section of track to cross over Pinnock Hill Roundabout and continues south to an at grade stop at Fosterstown. The alignment then continues southwards along the east side of the R132 and then descends to cross under the R132 just south of the junction at Airside and Boroimhe. The alignment emerges from the underpass, to rise to the surface and onto embankments through a greenfield area.

4.7 In this area groundborne noise and vibration do not require special consideration in the absence of sensitive buildings very close to the track.

Area MN103 Dublin Airport

4.8 The alignment enters two bored tunnels to the north of Dublin Airport. An underground stop, Airport, is located on this tunnelled section close to the existing airport terminal and the second terminal currently under construction. There is equipment at the airport potentially sensitive to vibration. St. Columcille Church is approximately 60m from the nearer tunnel.

Area MN104 Dublin Airport south portal to Santry Avenue

4.9 South of the airport perimeter road, the alignment emerges from tunnel and rises to surface level. The alignment crosses the M50, associated slip roads, and Old Ballymun Road on bridges and proceeds south descending to surface level at Northwood, which is an at grade stop located near Santry Lodge. South of Northwood Stop, the alignment descends into a cut and cover tunnel along the median of the R108 (Ballymun Road). This tunnel passes under Santry Avenue.

Area MN105 Santry Avenue to Albert College Park

4.10 The alignment continues southwards in a cut and cover tunnel beneath Ballymun Road, to a shallow underground stop at Ballymun, adjacent to the new civic plaza. Continuing south in a cut and cover tunnel along the Ballymun Road, crossing under Collins Avenue, the next stop is a shallow underground stop at DCU on the east side of Ballymun Road beside Albert College housing estate.

4.11 Ballymun town centre area is sensitive to vibration including protected structures such as St. Pappins Church. The Axis theatre is in Main Street. In Ballymun Residential Areas there is existing vibration where traffic calming devices have been placed in the road.

Area MN106 Albert College Park to Mater Stop

4.12 The alignment continues in a cut and cover tunnel across Albert College Park, entering twin bored tunnels near the southern boundary of the Park. The alignment remains underground in bored tunnel until its termination at St. Stephen's Green.

4.13 All educational and community landuses within this area are vibration sensitive as are Hampstead Private Hospital and Elmhurst Convalescent home. There is existing vibration where traffic calming devices have been placed in the road. The area is generally a high sensitivity area both to vibration and structure-radiated noise due to the dominance of residential and community and educational uses. The area around St. Patricks College has an overall high sensitivity due to its educational and residential landuses. Clonliffe College Estate and Holy Cross College have high sensitivity due to educational, religious and amenity uses. The tunnel passes below Corpus Christi school. In Drumcondra and Mountjoy Residential areas sensitivity is high as majority of the area is used for both residential and community uses. There is some existing vibration close to the railway at Drumcondra.

Area MN107 Mater Stop to St. Stephen's Green

4.14 South of the Mater Hospital the alignment passes under the Dorset Street/North Frederick Street junction and on to Parnell Square East where a cut and cover stop, Parnell Square (Rotunda), will be constructed. To the south of Parnell Square, the alignment proceeds in tunnel under O'Connell Street to O'Connell Bridge Stop. This stop is located under the River Liffey. From O'Connell Bridge the alignment proceeds beneath Westmoreland Street and College Green and under buildings between Clarendon Street and Grafton Street. The terminus stop, St. Stephen's Green, is located in the north west corner of the Green.

4.15 The Mater Hospitals have high sensitivity to vibration due to the presence of highly sensitive equipment. The overall sensitivity associated with this mixed use area is high due to the high residential component in the area. The educational, institutional and community facilities in the area are also sensitive to structure-radiated noise and vibration. There are various protected monuments and structures included throughout area, many Georgian buildings, the Rotunda Hospital, Gate Theatre and the Ambassador Theatre. The Gaeilscoil Colaiste Mhuire is in Parnell Square.

4.16 The hotels in and near O'Connell Street are sensitive to vibration and structure-radiated noise, as are office and commercial uses. O'Connell Bridge is a designated protected structure and the area is an Architectural Conservation Area. The baseline noise climate in O'Connell Street is elevated due to road traffic, and there is some baseline vibration near the intersection with the Luas Red Line.

4.17 The area around Henry Street has a high proportion of over-the-shop accommodation which is vibration sensitive as are educational or institutional uses. Commercial buildings have a lower sensitivity to vibration. Many sites have a protected structure designation. Baseline vibration is limited to effects of road traffic which is normally only significant when there are deformities in the paving.

4.18 The area around Trinity College Dublin is an important educational and nationally important area with high sensitivity to structure-radiated noise and vibration. There is existing vibration where traffic calming devices have been placed in the road.

4.19 Grafton Street and surrounding retail/commercial uses include the hotels, hostels and limited residential apartments over shops/offices are sensitive to structure-radiated noise and vibration.

4.20 The St. Stephen's Green area includes educational uses, hotels including the Westbury and Fitzwilliam Hotels and also protected structures with residential use, sensitive to structure-radiated noise and vibration. The Gaiety Theatre is in King Street South.

5.0 CHARACTERISTICS OF THE PROPOSAL WITH RESPECT TO GROUNDBOURNE NOISE & VIBRATION

Area MN101: Belinstown Depot to Swords Stop

5.1 The alignment is either at grade, on viaduct probably made of pre-cast segments or in a short cut-and-cover underpass with no construction techniques involving significant vibration expected. In the residential sections the alignment is in the central reservation of the existing highway. Earthworks are required to construct the depot. Excavation, concrete casting and backfilling will be required for the Malahide underpass.

5.2 It is proposed to cast a 300mm thick concrete slab over the existing Lissenhall bridge and the Balheary bridge.

5.3 The at-grade track will be ballasted, or slab track south from Malahide underpass

Area MN102: Swords Stop to Dublin Airport north portal

5.4 The alignment is either at grade, on a viaduct over Pinnock Hill roundabout, on embankments or in shallow cuttings, or in a short underpass with no construction techniques involving significant vibration expected. In the main residential sections the alignment is in the central reservation of the existing highway.

Area MN103: Dublin Airport

5.5 The alignment is in bored tunnel beneath the airport. The tunnel is in rock as is the stop structure, and construction methods may involve drilling and blasting with potential vibration effects.

Area MN104: Dublin Airport south portal to Santry Avenue

5.6 South of Northwood Stop, the route descends into a cut and cover tunnel along the median of the R108 (Ballymun Road) passing 21m from the nearest house in Coultry Road.

Area MN105: Santry Avenue to Albert College Park

5.7 The route continues southwards in a cut and cover tunnel beneath the Ballymun Road, passing 24m from the nearest house in Gateway View and 4m from the nearest house in Ballymun Road, to a shallow underground stop at Ballymun. The route continues along the Ballymun Road, crossing under Collins Avenue, to the DCU Stop where the nearest house is 2.5m from the tunnel.

Area MN106: Albert College Park to Mater Stop

5.8 The bored tunnel, likely to be constructed using a TBM, begins at Albert College park where the TBM will be launched, and passes in the glacial till (boulder clay) above the limestone beneath Hampstead Park entering the limestone at Hampstead Avenue. South of Griffith Avenue is a residential area and the Corpus Christi school directly above the tunnel with approximately 26m of ground cover. Tram speeds reach up to 70 km/h. Under the Sports Ground of St. Patrick's College there is a crossover, and the nearest house is 22m to the west with 32m of ground cover.

5.9 The tunnels pass below the St. Patrick's Schools in Millbourne Avenue and Drumcondra Library, and to the east of Chapelgate. There is approximately 16m of ground cover above the tunnel at Drumcondra.

5.10 South of Drumcondra the tunnels pass beneath mixed uses including residential buildings, and rise out of the limestone into the glacial till some 140m north of Mater Stop.

Area MN107: Mater Stop to St. Stephen's Green

5.11 At Mater Stop the bored tunnels are in the glacial till (boulder clay) overlying the limestone, and the stop box is founded on the limestone which is at a depth of about 20m. The existing Mater Private Hospital has piled foundations. The proposed future Mater Adult Hospital will have a raft foundation.

5.12 South of Mater Stop, the bored tunnels enter the limestone at approximately St. Joseph's Parade and pass under residential areas north of Parnell Square, The educational, institutional and community facilities in the area are also sensitive to structure-radiated noise and vibration. There are various protected monuments and structures included throughout the area. These include the Abbey Church, the Rotunda Hospital including the HARI Clinic, the Ambassador Theatre, the Temple Theatre and the Gate Theatre in Cavendish Row. The depth of the tunnel at Parnell Square is approximately 22m, and the presence of these receptors will require the installation of floating slab track or other special track support technology as far as Parnell Street in order to avoid a significant groundborne noise or vibration effect.

5.13 From Parnell Square to O'Connell Street the tunnel is in glacial sands and gravels, re-entering the limestone for the remainder of the route. The sensitive receptors are the hotels in O'Connell Street. There depth of the tunnel is approximately 24m.

5.14 From O'Connell Bridge to St. Stephen's Green there are buildings with residential use and the academic buildings in Trinity College. There is a crossover proposed close to Trinity College, and the added effect of the passage of wheels over the frogs in the switches will potentially increase the level of groundborne noise above the threshold of high impact for the uses of the spaces within Trinity College.

5.15 The Gaiety Theatre is in King Street South. The tunnel depth is approximately 25m (increasing towards St. Stephen's Green).

6.0 ASSUMPTIONS & METHODOLOGY

Construction

6.1 The predictions and assessment of construction vibration are based on assumptions about the likely construction methodology, and the plant to be used. Details of the actual plant and methodology will not be known until the contract is awarded.

6.2 As far as tunnelling is concerned, the principal assumption is the use of a tunnel boring machine (TBM). The principal sources of vibration from tunnel boring are probe drilling (if undertaken) and the cutting action of the TBM. The Dublin Port Tunnel was bored through bedrock that is similar to that which is expected to be experienced by the TBMs involved in the proposed scheme. During the course of the construction of the Dublin Port Tunnel, the project carried out extensive monitoring of the groundborne noise and vibration that occurred at specific locations along the scheme.

6.3 A numerical model of the Dublin Port Tunnel project has been created as part of the Metro North studies. The results of this model have been backfitted to the groundborne noise and vibration results that were measured when the port tunnel was being built in order to obtain a source term for the tunnel face. A comparative modelling exercise has then been carried out to create a model for Metro North taking into account the fact that the Metro North tunnel will have a significantly smaller diameter (approximately 6.7m) than that of the Dublin Port Tunnel (approximately 11m). The output of the modelling exercise provides an indication of likely ground vibration and associated groundborne noise at various depths and geological conditions, as well as a prediction of the decay of vibration and groundborne noise with distance, both laterally and ahead and behind the TBM.

6.4 Some underground construction within the limestone bedrock, for example the excavation of cross-passage, may be carried out by the use of drill and blast techniques. The principal source of vibration from drilling and blasting is the detonation of explosive charges underground. Vibration is a well known effect of blasting and empirical techniques for predicting the magnitude based on measurements in comparable lithology are well established. Blasting normally involves a sequence of detonations of small charges, separated by delays of 50 milliseconds or more in order to spread the vibration over a longer period and reduce the peak vibration amplitude.

6.5 Other sources of construction vibration are normal civil engineering plant, including machines for diaphragm walling, augurs, rock breakers and jackhammers. For the construction of the temporary bridge at the Liffey near O'Connell Street some percussive pile insertion is assumed.

6.6 For the prediction of vibration from the plant and machinery assumed it is necessary to know the dynamic properties of the soil and rock present at and around the worksites and tunnel alignment. A major ground investigation programme has been carried out for Metro North, involving a large number of boreholes Surface geophysical surveys were carried out at many locations and seismic refraction profiling, multichannel analysis of surface wave profiling and microgravity surveys were carried out. The results of these surveys were used to determine the principal dynamic properties of density, shear wave speed and compression wave speed (through which shear modulus, compressive modulus are determined). Material damping in the soil (loss factor) is not measured in ground investigations and conservative assumptions were made based on theoretical considerations and data from the scientific literature.

Operation

6.7 Modelling of the likely vibration and groundborne noise from the operation of Metro North vehicles has been carried out using likely design and operational parameters for vehicles expected to be offered by prospective operators. The most important parameters are wheel/rail roughness, bogie unsprung mass, suspension stiffness and speed.

6.8 A particular feature of the operation of a newly designed railway is that the incorporation of resilient rail support and the use of welded rail have the result that significant effects due to vibration and groundborne noise are completely avoided provided that the appropriate form of track support is selected, and an adequate maintenance regime is followed. Resilient rail support has been established as the standard trackform for non-ballasted track and is the normal method of standard rail support for modern urban underground railways throughout the world. While resiliently embedded rail is used for street-running, resilient baseplates or other rail support systems, or booted blocks are typical modern designs. The assessment of vibration and groundborne noise from a new railway therefore consists entirely of a consideration of the likely nature of incorporated mitigation in the design and operation (including maintenance) of the system. It is assumed that the following specification will be imposed:

(a) To ensure that noise disturbance during operation of Metro North is minimised, InfraCo shall ensure that the maximum permissible level of groundborne noise that may be generated during operation does not exceed 40dB $L_{Amax,S}$ determined near the centre of any occupied sensitive room of an inhabited building, except at the following locations:

(i) Between Parnell Street and Albert College Park the maximum permissible Groundborne noise that may be generated during operation does not exceed 25dB $L_{Amax,S}$ determined near the centre of any occupied sensitive room of an inhabited building.

(b) An inhabited building is a building which is in whole or in part lawfully used either temporarily or permanently as a dwelling, hospital, hostel or hotel. An occupied sensitive room is a room in an inhabited building that is a hospital ward, living room, or bedroom which is not a kitchen, bathroom, WC or circulation space that is in use as a living room or bedroom at the time the works are being carried out.

6.9 Mitigation measures primarily consist of the design of the track support system, and the choices available broadly fall into two categories, namely resilient rail support and floating slab track. Resilient rail support may be in the form of a resilient baseplate supporting the rail foot, a resilient support for the rail web instead of the rail foot, or the provision of a resilient boot to a concrete block to which the rail is fastened. Floating slab track (FST) means the support of the rail from a concrete slab which is mounted on resilient bearings. FST achieves greater isolation of vibration and groundborne noise largely because the mass of the concrete slab enables a lower natural frequency to be achieved without excessive dynamic deflection. Some of the vibration is also stored and dissipated in the slab and components above the slab.

7.0 ASSESSMENT CRITERIA

7.1 The criteria for assessment of groundborne noise and vibration are set out in Chapter 5 of each book in Volume 2 of the EIS.

Groundborne Noise

7.2 The metric which is widely used for the assessment of groundborne noise is the maximum A-weighted sound level using 'slow' time response, $L_{Amax,S}$. The symbol ‘L’ indicates a value expressed in decibels (abbreviated dB). The dB scale measures relative magnitudes of sound power or intensity (sound power per unit area) a property proportional to the mean squared value of the amplitudes of the air pressure oscillations that cause sound. Every doubling of intensity is a 3dB increase and every tenfold increase in intensity is a 10dB increase. A standard reference level (0dB = 20μPa of root mean square sound pressure) is used so that the dB scale can measure absolute levels as well as relative levels. The symbol ‘A’ signifies that the measured sound pressure has been subjected to frequency weighting using the standard ‘A-weighting scale’, to approximate the frequency response of the human ear—relatively insensitive at low frequencies and very high frequencies. Every 10dB increase in A-weighted sound level is perceived as approximately a doubling of loudness—slightly more than a doubling for sound of low frequency. The symbol ‘S’ specifies a method of averaging the oscillating sound pressure, by exponential averaging as defined in IEC 61672 (2002), using the standard ‘slow’ time constant of one second—the alternative being the ‘F’ or ‘fast’ time constant of 1/8 second. ‘S’ has a greater smoothing effect on sound that varies in level. The symbol ‘max’ means the highest averaged value reached during an event such as the passage of a train. The value of $L_{Amax,S}$ nearly equals the value of $L_{Amax,F}$ for a steady sound that lasts for one second or more, otherwise $L_{Amax,F}$ levels exceed $L_{Amax,S}$ levels by an amount dependent on the rapidity and magnitude of the variations. For groundborne noise from a modern underground railway $L_{Amax,S}$ levels are typically 2dB lower than $L_{Amax,F}$ levels.

7.3 During the construction phase, vibration will relate principally to the passage of the tunnel boring machine (TBM) and will be experienced by humans as groundborne noise. The fact that the TBM will only be heard in each tunnel for the short period of its passage means that impact thresholds are higher than for the permanent effect of the operating scheme. In limestone, the TBM is likely to advance at the rate of about 75m per week, operating 5 days per week. In the case of the Dublin Port Tunnel noise from the TBM was sometimes audible for up to three weeks before, and three weeks after, reaching the closest point to a receiving location. The Dublin Port Tunnel is approximately 11m in diameter. The Metro North tunnels will be 6.7m in diameter so groundborne noise levels will be less than those for the Dublin

Port Tunnel with consequently shorter durations. Passage through the overburden above the limestone is likely to be faster. In locations between the two tunnels, this experience will be repeated with a delay of the order of two months between the two tunnel drives. Because of the finite duration of this effect, the night-time impact thresholds have been set 5dB higher than those for the operation of the proposed scheme. Separate day-time thresholds (not relevant to operation as there is no difference between $L_{Amax,S}$ for a passing tram by day or night) have been used which are 5dB above the night-time thresholds (i.e. 10dB above the thresholds for operation).

Vibration

7.4 For the vibration assessment in the Metro North EIS one of the key stages was the choice of methodology for the measurement and assessment of human exposure to environmental vibration.

7.5 There is no Irish Standard for human exposure to vibration in buildings. The relevant British Standard was undergoing major revision during the preparation of the EIS. The decision was made to use the German DIN standard DIN 4150 instead.

7.6 DIN 4150-2:1999-06 (which is available in English) has many advantages. It has separate criteria for operational and construction vibration and has 5 categories of guideline values according to the location of the building. It has separate guidance for vibration due to road traffic, rail traffic, short-term vibration (e.g. blasting) and construction. For rail traffic it has separate guidance for underground rail traffic, surface urban transportation and surface traffic other than urban transportation.

7.7 The metric which is used for the assessment of vibration is the KB value from DIN 4150-2, which is assessed using three different criteria, A_u, A_o and A_r. the KB value is a frequency weighted measure of vibration velocity in units of mm/s, using the ‘F’ time constant, obtained for each 30-second cycle in a sequence of contiguous 30-second cycles. Two types of parameters are defined based on the KB value: - KB_{Fmax} the maximum value for the time varying KB value during the evaluation period; - KB_{FTr} an evaluation parameter that is weighted according to the number of vibration events and the duration of these events during the evaluation period. For daytime vibration other than blasting, if KB_{Fmax} is lower than or equal to A_u DIN 4150-2 states that 'the requirements of the standard have been met'. If KB_{Fmax} is greater than A_o 'the requirements of the standard have not been met'. In other cases, where the KB_{Fmax} value is between A_u and A_o, KB_{FTr} is calculated as the root-mean square of the 30- second KB values, and if it does not exceed A_r the 'requirements of the standard have been met'.

7.8 For construction vibration three levels are defined by DIN 4150-2:

(a) Level I: With vibration below this level, it can be assumed even without any previous knowledge, that there will be no considerable discomfort. In this assessment daytime vibration impact above Level I and not above Level II is classed as Low.

(b) Level II: Vibration below this level is also not likely to produce considerable discomfort, as long as the measures specified in DIN 4150-2 are taken. As this level is exceeded, the probability increases that there will be considerable discomfort. According to DIN 4150-2 'If it is expected that level II will be exceeded, an attempt shall be made to use construction methods that produce less vibration'. In this assessment daytime vibration impact above Level II and not above Level III is classed as High.

(c) Level III: The effects produced by vibration above this level are unacceptable.

7.9 In this assessment daytime vibration impact above Level III is classed as Very high. For construction vibration at night, the same guideline values used for operational vibration apply. In this context DIN 4150-2 defines criteria for five receptor types and the most stringent criteria have been used to define the Very low impact category. The criteria for less sensitive receptors defined in DIN 4150-2 have been used to define the higher impact magnitudes in the absence of other guidance.

7.10 For assessment of vibration from blasting, the metric conventionally used is peak particle velocity (PPV). The Irish EPA recommends that to avoid any risk of damage to properties in the vicinity of a quarry, the vibration levels from blasting should not exceed a peak particle velocity of 12mm/s as measured at a receiving location when blasting occurs at a frequency of once per week or less. In the rare event of more frequent blasting, the peak particle velocity should not exceed 8mm/s. DIN 4150-2 uses KB_{Fmax} for the assessment of human exposure to vibration from blasting, using only the A_o values from the set of limits (A_o, A_u and A_r) used for general vibration assessment. A daytime value of $A_o = 6$ is equated in the EIS to the threshold of High impact. The threshold of Medium impact is $A_o = 5$ and Low impact is $A_o = 3$, being the daytime A_o value given in DIN 4150-2 for the two most sensitive classes, 'Buildings which are predominantly or purely residential' and 'Buildings in specially protected areas'. Vibration from construction plant operating on above-ground worksites is assessed in the same way as vibration from the tunnelling.

7.11 All impact magnitudes above 'low' are defined as significant. All impact magnitudes above 'very low' are defined as significant at night.

8.0 POTENTIAL IMPACTS OF PROPOSAL

Area MN101: Belinstown Depot to Swords Stop

8.1 Low construction vibration impacts are likely in this section. For operation, very low vibration or groundborne noise impacts are likely with standard resilient rail support.

8.2 With suitable vibration isolating trackform vibration damage to the bridges at Lissenhall can be avoided.

Area MN102: Swords Stop to Dublin Airport north portal

8.3 Low construction vibration impacts are likely in this section. For operation, very low vibration or groundborne noise impacts are likely with standard resilient rail support.

Area MN103: Dublin Airport

8.4 No additional vibration mitigation is required to avoid exceeding the vibration limits for the most sensitive equipment reported at the Airport.

Area MN104: Dublin Airport south portal to Santry Avenue

8.5 Low vibration impacts are likely from both construction and operation.

Area MN105: Santry Avenue to Albert College Park

8.6 There are likely to be medium vibration and groundborne noise impacts from the excavation of the cut-and-cover tunnel because of the short distances. Mitigation will involve selection of low-vibration methods of work, liaison with residents and monitoring. For operation there are likely to be medium vibration and groundborne noise impacts with standard resilient rail support.

Area MN106: Albert College Park to Mater Stop

8.7 During the passage of the tunnel boring machine, the groundborne noise level is likely to cause a high impact in the residential area if tunnelling takes place at night, medium impact if tunnelling does not occur at night.

8.8 There is a proposed cross passage to the east of The Rise, which has approximately 16m of ground cover (78m slant distance to the nearest residential buildings) and vibration during its construction is likely to be in the low impact category for people in the building.

8.9 There is a proposed cross passage near Bantry Road, which has approximately 19m of ground cover (323m slant distance to the nearest residential buildings). To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.10 Rock breaking will be required for the construction of Griffith Avenue Stop, and assuming this is done using a hydraulic rock breaker, Groundborne noise levels will result in low impact by day, medium impact by night.

8.11 There is a proposed cross passage at Home Farm Road, which has approximately 22m of ground cover (27m slant distance to Corpus Christi School and 23m slant distance to the nearest residential buildings). To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.12 There is a proposed cross passage to the east of Ferguson Road, which has approximately 27m of ground cover (38m slant distance to the nearest residential buildings). To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.13 Under the Sports Ground of St. Patrick's College there is a proposed crossover with 28m of ground cover, and the nearest house is 24m to the west. The crossover tunnel is proposed just to the south of the Ferguson Road cross passage. To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.14 During the passage of the tunnel boring machine, the groundborne noise level in this area is likely to cause medium impact if tunnelling takes place at night, low impact if tunnelling does not occur at night.

8.15 The tunnels pass below the St. Patrick's Boys National School in Millbourne Avenue and Drumcondra Library, and to the east of Chapelgate. There is approximately 28m of ground cover above the tunnel at Drumcondra Stop. Rock breaking will be required for the construction of Drumcondra Stop, and assuming this is done using a hydraulic rock breaker, groundborne noise and vibration levels will result in medium impact by day, high impact at night.

8.16 During the passage of the tunnel boring machine, the groundborne noise level in this area is likely to cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration is likely to cause high impact at night, very low impact by day.

8.17 There is a proposed cross passage near Woodvale Road directly below residential buildings, which has approximately 25m of ground cover. To limit the construction vibration to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.18 During the passage of the tunnel boring machine in this area, the groundborne noise level is likely to cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration is likely to cause high impact at night, very low impact by day.

8.19 There is a proposed cross passage near Carlingford Road directly below residential buildings, which has approximately 27m of ground cover. To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.20 There is a proposed cross passage under the Royal Canal, approximately 25m slant distance from the nearest residential buildings in St. Ignatius Road. To limit the construction vibration to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.21 There is a proposed cross passage near Kenmare Parade directly below residential buildings, which has approximately 19m of ground cover. To limit the construction impact due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.22 During the passage of the tunnel boring machine in this area, the groundborne noise level is likely to be cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration is likely to cause high impact at night, very low impact by day.

8.23 For operation very low vibration or groundborne noise impacts are likely with standard resilient rail support.

Area MN107: Mater Stop to St. Stephen's Green

8.24 The Mater Private Hospital will be in normal use during the construction of the Mater Stop and the tunnel drive. The southern headwall of the stop is proposed at approximately 2m from the Mater Private Hospital. Vibration will be transmitted into the foundations from the excavation of the limestone at the base of the stop box, from concreting of the headwall which may include breaking out a soft eye in the headwall to admit the tunnel boring machine (TBM). Vibration from the passage of the tunnel boring machine will be transmitted through the ground to the hospital foundations. Vibration, once it has entered the hospital structure, will decay only slightly with distance, although it would require on-site tests to establish the effect of distance within the structure.

8.25 The limit for sensitive equipment in the Mater Hospitals will be significantly exceeded in the Private Hospital, by a factor of the order of 25, during the passage of the tunnel boring machine, and the limit will not be achieved until the TBM is of the order of 350-400m from the hospital. This amounts to some 10 weeks for each tunnel at a progress rate of 75m per week, although in the overburden the progress rate may be faster. Special arrangements will be required for the most sensitive equipment in the hospital. The existing Mater Adult Hospital also lies within this distance.

8.26 Depending on the vertical alignment, rock breaking may be required for the construction of Mater Stop, and assuming this is done using a hydraulic rock breaker, groundborne noise levels are likely resulting in medium impact on humans by day, high impact by night, but some 17 times the sensitive equipment limit of 12 mm/s.

8.27 Blasting for the Kenmare Parade cross-passage will occur about 280m from the Mater Private Hospital is likely to give a PPV of 0.75mm/second at the hospital. This would interfere with the operation of sensitive equipment, and mitigation in the form of liaison between the site and the hospital will be required to ensure that blasts and critical use of the equipment do not occur simultaneously. The equivalent value is in the very low category for day; high for night.

8.28 There are residential buildings immediately above the cross-passage at St. Joseph's Place where there is approximately 25m of ground cover. To limit the construction impact from blasting to the low impact category for daytime the charge weight per delay would have to be restricted to 0.9kg.

8.29 During the passage of the tunnel boring machine in this area, the groundborne noise level is likely to cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration is likely to be cause high impact at night, very low impact by day.

8.30 During the passage of the tunnel boring machine in this area, the groundborne noise level is likely to cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration is likely to cause high impact at night, very low impact by day. The effect of the tunnel boring machine in the theatres will depend on the nature of the production. During quiet moments in a production, this will be clearly audible and intrusive.

8.31 There is a planned cross passage opposite Hardwicke Street, just south of Telecom Éireann. Ground cover is approximately 26m and vibration in excess of the damage threshold for computer equipment may occur. This cross passage is approximately 300m from the HARI clinic to give a PPV of 0.7mm/second at the clinic. This would be close to the limit advised for the operation of sensitive equipment at the Rotunda Hospital/HARI clinic, and mitigation in the form of liaison between the site and the hospital together with vibration monitoring will be required to ensure that use of the equipment is not adversely affected.

8.32 The HARI/Rotunda vibration threshold for sensitive equipment is not likely to be exceeded by the passage of the tunnel boring machines. The groundborne noise level is likely to cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration from the tunnel boring machine is likely to cause high impact at night, very low impact by day. Some works for the construction of the Parnell Square Stop, including enabling works involving service diversions, will involve construction activities a very short distance from the nearest part of the HARI unit. Special measures will be required to avoid disturbance of vibration sensitive equipment while these activities are taking place. Groundborne noise is likely to have a high impact in the Gate Theatre during performances.

8.33 Rock breaking will be required for the construction of Parnell Square Stop, and assuming this is done using a hydraulic rock breaker, Groundborne noise and vibration is likely to result in low impact by night, very low impact by day, although special measures will be needed to avoid affecting vibration sensitive equipment in the HARI unit.

8.34 There is a proposed cross-passage below O'Connell Street Upper. Its construction would interfere with the operation of sensitive equipment at the HARI Clinic, and mitigation in the form of liaison between the site and the hospital will be required to ensure that blasts and critical use of the equipment do not occur simultaneously.

8.35 The proposed cross-passage below O'Connell Street Upper with approximately 21m of ground cover (26m slant distance to the nearest building). To limit the construction vibration to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.36 Enabling works including utility diversions on O'Connell Street and Westmoreland Street have the potential to cause vibration, and control measures will be required to avoid significant effects.

8.37 Drill and Blast may be necessary for the construction of O'Connell Bridge Stop beneath the Liffey. To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.38 During the passage of the tunnel boring machine in this area, the groundborne noise level is likely cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration is likely to be cause high impact at night, very low impact by day.

8.39 There is a proposed cross passage near Princes Street North, which has approximately 23m of ground cover (25m slant distance to the nearest building). To limit the PPV to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.40 There is a proposed cross passage near College Green, which has approximately 23m of ground cover (30m slant distance to the nearest building). To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.41 During the passage of the tunnel boring machine in this area, the groundborne noise level in the nearest buildings of Trinity College is likely to cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. The noise will be clearly audible in Trinity College and intrusive in quiet rooms occupied by people engaged in activities requiring concentration or relaxation. Vibration is likely to cause medium impact at night, very low impact by day.

8.42 There is a proposed cross passage near Wicklow Street, which has approximately 24m of ground cover. To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8.43 During the passage of the tunnel boring machine in this area, the groundborne noise level is likely to cause high impact if tunnelling takes place at night, medium impact if tunnelling does not occur at night. Vibration is likely to cause high impact at night, very low impact by day.

8.44 From operation. very low vibration or groundborne noise impacts are likely with standard resilient rail support in this area.

8.45 The Gaiety Theatre is in King Street South and groundborne noise will cause a high impact during performances. The effect in the theatre will depend on the nature of the production. During quiet moments in a production, it will be clearly audible and intrusive. The main mitigation possible is liaison with the theatre managements, with as much advance warning as practicable. For operation the use of floating slab track will be required to avoid a significant ground-borne noise effect.

8.46 At St. Stephen’s Green, blasting is likely to be used for the excavation of the turnback loop. There is approximately 20m of ground cover, and the shortest slant distance to the nearest the nearest property is 50m. To limit the construction vibration due to blasting to the low impact category for daytime the charge weight per delay would have to be severely restricted.

8. REMEDIAL OR MITIGATION MEASURES

Operation

8.47 Engineering design techniques are available to reduce groundborne noise and vibration from the operation of an underground railway system such as Metro North. Mitigation will consist of the identification of sensitive receptors according to the categories set out in the assessment criteria of Chapter 5 of each book in Volume 2 of the EIS, the setting of specified limits to ensure that groundborne noise and vibration does not reach the “medium impact classification and requiring the design and installation of the appropriate degree of vibration isolation in the track support system.

8.48 The categories for which limits apply are dwellings, offices, hotels, schools, colleges, hospitals, libraries, places of meeting for religious worship, courts, lecture theatres, auditoria, theatres and concert halls. Places with sensitive equipment are considered on a case by case basis.

Construction

Vibration effects on buildings and monuments

8.49 For buildings in general, it will be specified that vibration expressed in terms of PPV shall not exceed the low impact category, namely 5mm/s necessitating that the contractor uses construction methods which ensure that risk of damage to buildings is minimised. For vulnerable or historic buildings lower limits will be applied, determined by case by case basis.

Vibration effects on building occupants

8.50 As explained in the EIS, not all significant effects can be mitigated. However, the effect of groundborne noise and vibration from the tunnel boring machine can be limited to avoid a significant effect at night by allowing the tunnelling contractor to work at night only if appropriate night time noise limits can be achieved.

8.51 Mitigation of effects on the high-sensitivity locations, particularly the Mater and Rotunda Hospitals will be a combination of engineering measures such as low-vibration methods of rock breaking and liaison and cooperation between the worksites and the hospitals to avoid carrying out of activities which might cause vibration sufficient to have a significant effect on the operation of sensitive equipment and procedures.

9.0 PREDICTED, REMEDIAL IMPACTS AND SUMMARY

9.1 The following table summarises the overall residual impacts.

Source	Significance of impact without mitigation	Mitigation	Magnitude of impact taking into account mitigation	Significance of impact
Construction phase				
Goundborne noise (TBM)	Significant		Medium by day	Significant
	Significant	Specified night time maximum limit	Low by night	Significant
Vibration affecting humans (TBM)	Not Significant		very low by day	Not Significant
	Significant	Specified night time maximum limit	low by night	Significant
Vibration affecting buildings and structures (TBM)	Significant	Specified maximum vibration limits	Low	Not Significant
Vibration affecting sensitive	Significant	Liaison and cooperation to avoid	Low	Not Significant

Source	Significance of impact without mitigation	Mitigation	Magnitude of impact taking into account mitigation	Significance of impact
receptors equipment (TBM and other construction plant)	Significant	operation of plant during sensitive uses.		
Vibration affecting humans (drill and blast) very high	Significant	Specified maximum vibration limits	Low	Not Significant
Vibration affecting buildings and structures (drill and blast) high	Significant	Specified maximum vibration limits	Low	Not Significant
Vibration affecting sensitive receptors and equipment (drill and blast)	Significant	Liaison and cooperation to avoid blasting during sensitive uses.	Low	Not Significant
Operational phase				
Goundborne noise	Not significant	Specification and design	low or very low	Not significant
Vibration affecting humans	Not significant	Specification and design	very low	Not significant
Vibration affecting sensitive equipment	Not significant	Specification and design	very low	Not significant

10.0 RAILWAY ORDER CHANGES

10.1 Since the publication of the EIS there have been some changes made to the scheme. I have reviewed these and assessed their potential vibration impacts. The majority of the changes that involve revised designs do not move structures and facilities and will not change vibration or groundborne noise impacts during the construction or operation of the Metro. The scheme change that could affect vibration and groundborne noise impacts is discussed below.

10.2 Relocation of Escalators on St. Stephen's Green.

10.3 The relocation of the escalators northwards on St. Stephen's Green West will reduce vibration and groundborne noise at the Fitzwilliam hotel during their construction.

11.0 CONCLUSION

11.1 For the construction of the Metro, RPA will put in place a series of procedures that will ensure that internationally accepted vibration limits are not exceeded. These procedures will involve a process of prediction, specification, monitoring and contractual controls. Vibration that causes groundborne noise will also be controlled to avoid exceedance of widely accepted limits at night, but during the day there will be unavoidable disturbance for a limited duration during the passage of the tunnel boring machines.

11.2 In the case of receptors specially sensitive to vibration and groundborne noise, including the hospitals and their vibration-sensitive equipment, special measures will be taken in cooperation with the parties concerned to ensure both that there is no disturbance to the operation of the equipment, but also no significant effect on the equipment when not in use. The measures will include prediction, specification, monitoring and contractual controls, and if necessary relocation of sensitive equipment.

11.3 For the operating Metro, well-established vibration isolation measures will be included in the trackform design to ensure that widely accepted limits for vibration and groundborne noise will not be exceeded, both for residents and for locations and installations specially sensitive to vibration and groundborne noise.

Evidence of Rupert Thornely-Taylor

Groundborne Noise and Vibration

Additional text at paragraph 8.25

At the time of the preparation of the EIS, a study was carried out to predict the highest levels of vibration which would result from the passage of the tunnel boring machine (TBM) past the Mater Private Hospital. The results were presented in terms of the envelope of levels of vibration across the frequency spectrum likely to occur in any position within the hospital building.

Since completion of the EIS more detailed information has become available about the specific vibration sensitivities of individual items of equipment and their location within the building. It has been possible to refine the numerical predictions, with the result that the likely levels of vibration in many cases do not exceed the thresholds identified to the extent foreseen in the EIS. Subject to further verification and continuing studies to include more remote parts of the building, the indications are that with a process of specification, prediction, monitoring and control it will be possible for the TBM to complete its passage past the hospital within the vibration limits for sensitive equipment. The higher levels of vibration originally predicted will occur on the suspended upper floors of the hospital building, and vibration levels in the theatres on level 2, wards on levels 3 and 4, and eye lasers on level 5 would exceed criteria discussed with the hospital while the tunnel is within 50m (300m in the case of the eye lasers). Each of the two TBMs is expected to advance at the rate of about 75 metres per week. Tunnel boring occurs from the north, and south of the hospital boring does not resume until the southern end of the stop box (by then already constructed), some 165m away.

It appears that the eye lasers could be relocated without major disruption, in which case the significant effect from the TBMs would be confined to a period of less than two weeks.

Vibration will also potentially arise during stop box construction, and the effects are of the same order as those of the TBM. During construction of the section of diaphragm wall nearest to the hospital a similar process of specification, prediction, monitoring and control will be required to avoid exceeding vibration thresholds.

Vibration also causes groundborne noise, and during the passage of the TBMs secondary noise levels in the hospital areas will be up to 47 dBA, in excess of the long-term levels required in guidance for hospital acoustics (40-45 dB $LA_{eq,\ 1h}$ according to type of location) but not necessarily in excess of noise levels often found in hospital wards. This will occur for a period of the order of a week for each TBM. The second TBM will of course be more distant from the hospital with a smaller effect.

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