

Master Plan Noise and Ground Vibration Survey Performed at the Liverpool Hospital.

NOISE AND VIBRATION IMPACT ASSESSMENT

- Final
- 14 August 2006



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Executive Summary

A significant construction project has been proposed for the upgrading of the facilities in the Liverpool Hospital complex. The demolition and construction of several buildings is to be performed in close proximity to existing noise and vibration sensitive areas in buildings located around the construction site.

SKM was commissioned by the NSW Department of Commerce to identify and assess the existing acoustic and vibration environments in buildings that may be directly affected by the construction works and to identify and assess the acoustic and vibration environment for existing and proposed new buildings that may be directly affected by existing rail traffic and also for additional rail traffic resulting from the proposed Southern Sydney Freight Line and proposed additional commuter rail lines.

Environmental ground vibration and noise level measurements were performed in the hospital grounds to quantify the impact of train movements along the Eastern boundary of the Hospital grounds on the existing buildings and structures and also to determine the likely impact on the proposed buildings.

The existing vibration and acoustic environment of several work areas in buildings located near the proposed construction work site were quantified. In discussion with operators, critical acoustic and vibration sensitive work areas such as the operating theatres and the MRI unit which are located in the Clinical Building were also identified.

Ground vibration levels generated by train pass-bys were measured in the hospital grounds and found to be of a low magnitude and currently, these do not have an impact on any vibration sensitive areas.

The overall sound pressure levels generated during train pass-bys currently do not affect the ambient noise levels inside any of the work environments.

Due to the close proximity of the proposed construction works to vibration sensitive areas, careful consideration has to be paid to construction techniques and equipment. Maximum recommended vibration limits at the vibration sensitive areas and the maximum sound pressure levels that may be generated at the construction site have been quantified.

Three buildings titled Zone A, Zone F and the Engineering Services are proposed to be located in close proximity to the existing railway line and the proposed Southern Sydney Freight Line and fourth rail tracks. From the ground vibration level measurements performed in this assessment, the magnitude of the vibration levels currently generated during train pass-bys would not have significant impact on the environment in the proposed buildings. However, the acoustic

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performance of the facades facing the rail way tracks needs to be taken into account to achieve an acceptable acoustic environment in office areas and rehabilitation areas of these buildings.

It is also believed that the Southern Sydney Freight Line will be constructed on the Eastern side of the existing rail tracks and a fourth rail track will be constructed between the Up and Down train lines as a 'turn back'. Train speeds will be higher than at present going from approximately 50 - 60 KPH to 80 - 100 KPH for the commuter trains and 80 KPH for the freight trains. This will generate higher ground vibration levels at the current and proposed buildings than are currently observed. Our predictions show that ground vibration levels generated by three commuter trains and a freight train travelling at 100 and 80 KPH respectively on the assumption that the three train pass-bys occur simultaneously would still result in compliance with the strictest vibration criteria presented in BS 6472 : 1992.

The predicted sound pressure levels generated by train pass bys for the worse case at the proposed development zone A, zone F and Engineering Services building facades will result in a significant impact on the internal sound pressure levels within these buildings unless attenuated. Predicted sound pressure levels without noise mitigation would be in the order of 95 – 100 dBA at the external facades. These noise levels would last for a relatively short duration but would have a significant impact on the internal noise levels, especially in noise sensitive areas of the proposed Development Zone A building should these be located on the outer extremities of the building rather than inside.

Acoustic barriers could be used as a partial solution to reduce rail noise intrusion into the lower levels of buildings in the event that noise sensitive occupancies need to be located adjacent to exposed facades. However, where there is clear line of sight from the upper floor levels of Development Zone A building to the train tracks, the barrier will not significantly reduce the noise levels at the building facade. Therefore, careful consideration of the glazing, wall construction and openings will need to be given during the building detailed design phase so that an acceptable acoustic environment can be achieved. Preferably, noise and vibration sensitive equipment and work areas should be located away from the building facades, especially on the Eastern and Southern facades.

The operating theatres and MRI equipment need to be located in the centre of the building similar to the existing configuration in the Clinical Building.

It has been assumed the proposed SSFL track construction passing through the Liverpool Hospital complex is similar to the existing track configuration, that is, continuous welded track on timber sleepers on ballast. From the ground vibration measurements, this configuration would meet the strictest criteria BS 6472 : 1992 for hospital environments. Suburban train pass by noise levels are generated by the wheel / rail interaction and are strongly determined by wheel condition of the



trains while the freight trains noise levels are due to a combination of Diesel locomotive engine noise and wheel / rail interaction and exhaust noise.

A section of the SSFL track is to have approximately a 200 metres long concrete base built on 0.75m diameter piles at a depth of approximately 22 metres. This section of track is located between the Liverpool station and just south of the existing Elizabeth level crossing. This construction may have an impact on the ground vibration levels generated during freight train pass bys but a complete geological technical report and modelling would be required to determine the full impact.

During our site visit, there were no helicopter operations. Therefore no conclusions can be drawn in relation to existing helicopter noise and vibration impacts on the proposed buildings. However, the proposed location of the helicopter landing pad on top of the building adjoining the imaging building will require special attention during the detailed design to avoid adverse noise and vibration impacts.



1. Introduction

1.1 Overview

The NSW Department of Commerce commissioned Sinclair Knight Merz (SKM) to provide an environmental assessment of the existing ambient noise and vibration levels in sensitive areas of the Liverpool Hospital. This information was to be used in assisting the planning and early design of the proposed expansion.

The Liverpool Hospital is a multi building complex having boundaries defined by:-

- Campbell St. on the Northern boundary
- Goulburn St on the Western Boundary
- The railway line on the Eastern boundary
- Technical College on the Southern Boundary

Significant construction works for new facilities are to be performed in the existing Liverpool Hospital grounds. The proposed works include the demolition of a number of deteriorated hospital buildings and the construction of new buildings.

A third rail line on the hospital boundary is also proposed to be constructed in 2008.

This preliminary noise and vibration assessment report has been prepared as part of an environmental assessment for the proposed demolition and construction project based on initial project information.

Noise and ground vibration measurements were performed to assess the existing ambient noise and vibration levels due to train pass bys. Noise and building structure vibration measurements were also performed in the building interiors in critical areas such the operating theatres and beside MRI equipment located in the Clinical Building (Building 07).

The potential noise and vibration impacts associated with the proposed demolition and construction of hospital buildings in these critical areas can be presented as:-

- Airborne noise
- Structure borne noise or regenerated noise
- Ground borne vibration

The demolition and construction works are to be performed in close proximity to the Clinical Building and will involve the use of heavy equipment.

Airborne noise will be generated by demolition and construction equipment such as:-

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- Excavators
- Trucks
- Compressors
- Generators
- Front end loaders
- Concrete pumps
- Pile drivers
- Cranes

Ground vibration will be generated by heavy earth moving equipment such as:-

- Pile Drivers
- Vibratory rollers
- Mobile construction equipment

Structure borne or regenerated noise is caused by the excitation of the building structure by ground vibration generated by the construction equipment or demolition and construction operations. The building structure is structurally excited causing the floor windows and walls to radiate noise or cause objects like pictures on walls to rattle.

Appendix A presents a drawing of the proposed construction works for the Liverpool Hospital

1.2 Report Presentation

This report describes measurements and results pertaining to:-

- a) Base line vibration levels generated by train pass by along the Eastern boundary of the hospital boundary complex.
- b) An indication of the rate of attenuation of rail induced vibration through the ground.
- c) Typical ground vibration levels in the hospital grounds.
- d) Typical indoor ambient floor vibration levels at various vibration critical areas.
- e) Typical outdoor ambient noise levels within the hospital grounds.
- f) Typical outdoor ambient noise levels of train pass bys at the Eastern boundary.
- g) Typical indoor ambient noise levels inside various noise critical areas.

2. Measurement Locations

2.1 Train Pass By Ground Vibration Levels.

The ground vibration level measurements were performed in the grassed area near the Engineering Building (20b). A base line ground vibration measurement was performed at a distance of 15 metres from the UP line.

A simultaneous ground vibration measurement was performed at a second location, at a distance of 30 metres from the 'Up' line.

Ground vibration measurements were also performed at a third location 43 metres from the 'Up' line.

Ground vibration measurements were performed during a number of suburban train and freight train pass bys. Train pass by configurations included:

- a) Tangara 8 car sets ('up' & 'down')
- b) Millennium 8 car sets ('up' & 'down')
- c) Goninan 6 & 8 car sets ('up' & 'down')
- d) Freight train (up)

All vibration measurement were performed in the vertical axis only (Z axis).

2.2 Ambient Ground Vibration Levels

Ambient ground vibration measurements were performed in the courtyard of the Clinical Building (07) to obtain an indication of typical background vibration levels within the hospital grounds and in close locale to the to critical areas such as the MRI and Operating Theatres.

All vibration measurements were performed in the vertical axis only (Z axis).

2.3 Floor Vibration Levels in Critical Areas of the Clinical Building (Building 07)

Ambient floor vibration measurements were performed at two locations in the Clinical Building. Floor vibration measurements were performed in the MRI office adjoining the MRI Unit and vibration measurements were also performed in the Unit Nurses Manager's Office, which adjoins the operating theatres on the 3rd floor of the Clinical Building. Vibration measurements were taken at every 1 minute period continuously over approximately 20 hours at each measurement position. 'Footfall' measurements were also performed in the MRI area to determine the effect of pedestrian traffic on overall floor vibration levels.



The natural frequency of the floor was determined using an impact test and by measuring the floor response.

All vibration measurements were performed in the vertical axis only (Z axis).

2.4 Ambient Noise Levels in the Hospital Grounds

Ambient noise level measurements were performed at two locations in the Liverpool hospital grounds. Noise level measurements were performed in the grassed area directly outside the Brain Injury building and the Ron Dunbier building and also in the grassed area directly opposite the Mental Health Building where the proposed construction work is to be performed.

The day time ambient noise levels were measured over a minimum 15 minute time period in accordance to the Department of Environmental Conservation Guidelines for Construction Noise Emissions.

2.5 Train Pass By Noise Levels at the Eastern Boundary of the Hospital Grounds

Train pass-by noise level measurements were conducted at the fence line of the Eastern boundary of the Liverpool Hospital approximately 15 metres from the UP line.

The pass-by noise level measurements were performed during a number of suburban train pass-bys at various train speeds.

Train pass-by configurations included:-

- a) Tangara 8 car sets (up & down)
- b) Millennium 8 car sets (up & down)
- c) Goninan 6 & 8 car sets (up & down)

2.6 Building Interior Ambient Sound Pressure Levels.

Building interior sound pressure levels were measured at several locations in the Clinical, Mental Health and Brain Injury Buildings. Sound pressure level measurements were performed over a 5 – 10 minute period.

The sound pressure level measurement locations are listed below :

Clinical Building

- Hallway - Eastern facade beside Intensive Care Unit. (closest to the proposed construction site)
- Foyer of the operating theatres 2nd floor
- Hallway – South East facade level 5
- In the office adjoining the MRI unit

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- In the ICU ward (note continuously monitored for 20 hours)
- Helipad Apron (outdoor measurement / no helicopter)

Mental Health Building

- Foyer (directly beside proposed construction site works)

Brain Injury Building

- In office of Programme Co-ordinator (office faces directly onto the access road)

3. Measurement Instrumentation

3.1 Ground and Floor Vibration Level Measurements.

The vibration measurements were performed using a Bruel & Kjaer PULSE multi channel data acquisition and analysis system, which allows for the storage of detailed waveforms for post processing. The PULSE system was operated manually to capture each train pass by measurement. The approximate train speed was determined by timing the time taken for a train to pass over a known distance.

The ground vibration measurements were taken using a Bruel & Kjaer accelerometer type 3806 and a PCB accelerometer type 353E33. Each accelerometer was calibrated prior to the vibration survey.

The extended floor vibration measurements were also performed using the PULSE acquisition system in conjunction with the Bruel & Kjaer 3806 accelerometer (having a high sensitivity of 10v/g). Vibration measurements were logged every 60 seconds over the 19 – 20 hour measurement period at two vibration critical locations.

3.2 Sound Pressure Level Measurements

Sound pressure level measurements were performed at various locations using a Bruel & Kjaer Observer Sound Level Meter, type 2260. Statistical noise analysis was performed at each measurement location.

Long term noise level measurements were performed in the ICU ward over a 23 hour period using an ARL Type 215 Data Logger to monitor the typical ambient and maximum noise levels within the ICU ward.

4. Measurement Results

4.1 Vibration.

Vibration measurements were performed in critical areas of the Clinical Building on the building structure and ground vibration measurements were also performed to determine the impact of train pass by.

4.1.1 Ground Vibration Levels - Train Pass By.

Very low ground vibration levels were obtained on site. These were near the 'noise floor' of the PCB accelerometer, therefore only data obtained using the Bruel & Kjaer accelerometer, which has a much higher sensitivity, was used.

Figure 1 presents the ground vibration levels measured at the three measurement distances of 15, 30 and 43 metres from the rail line. The ground vibration amplitude for frequencies up to 200 Hz is presented for various train configurations and train speeds. The amplitude is plotted in logarithmic form.

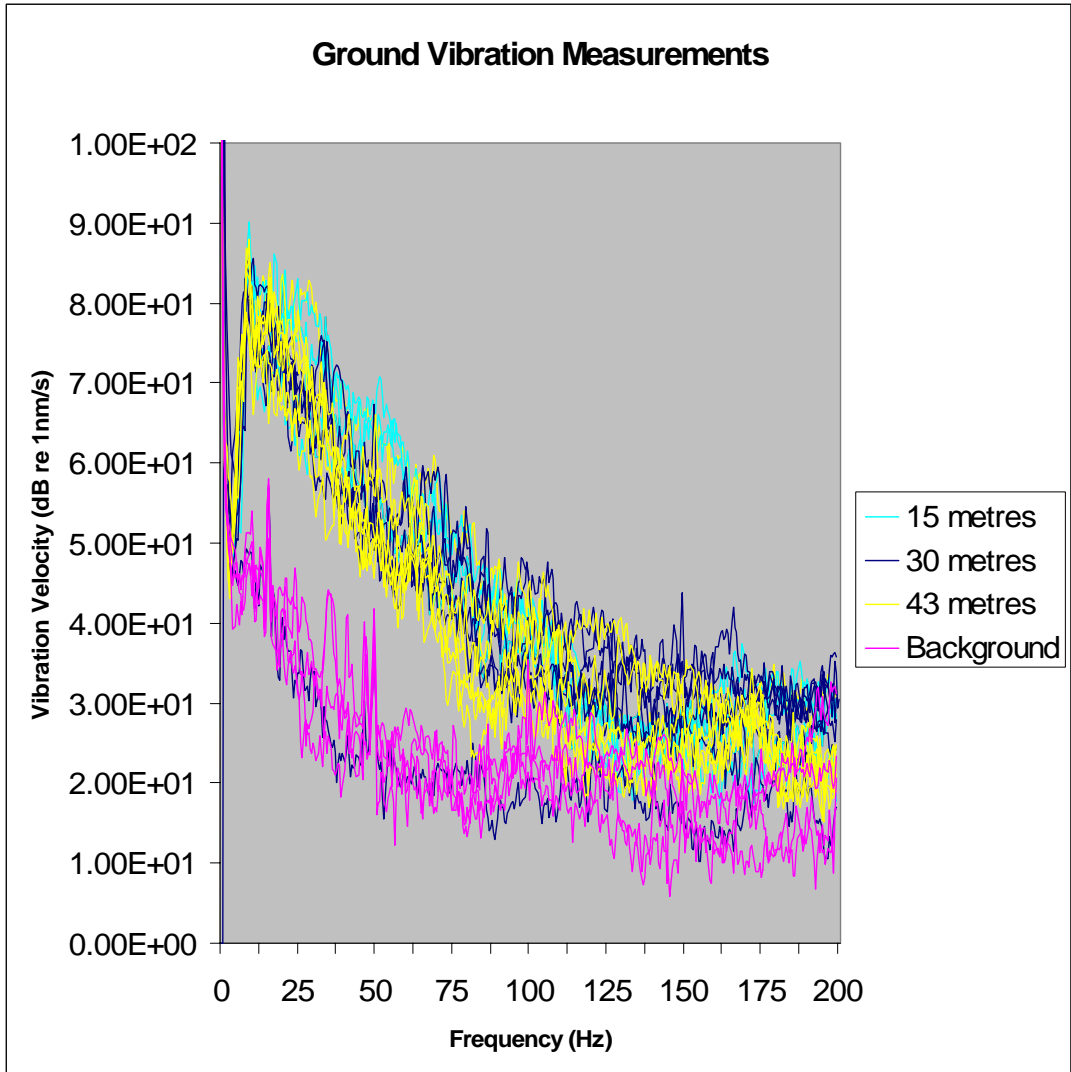


Figure 1

Figure 1 Ground Vibration Level at Various Distances from the train track versus frequency for different Train Pass By configurations and train speed. Ambient background ground vibration levels are also presented

Figure 2 below presents the typical ground vibration levels measured at the three measurement distances of 15, 30 and 43 metres from the rail line for a suburban train pass by at a speed of approximately 60 kph. The ground vibration amplitude for frequencies up to 200 Hz is again presented in logarithmic form.

The existing background ambient ground vibration levels are also presented for the condition of "no train pass-by" as a baseline for comparison.

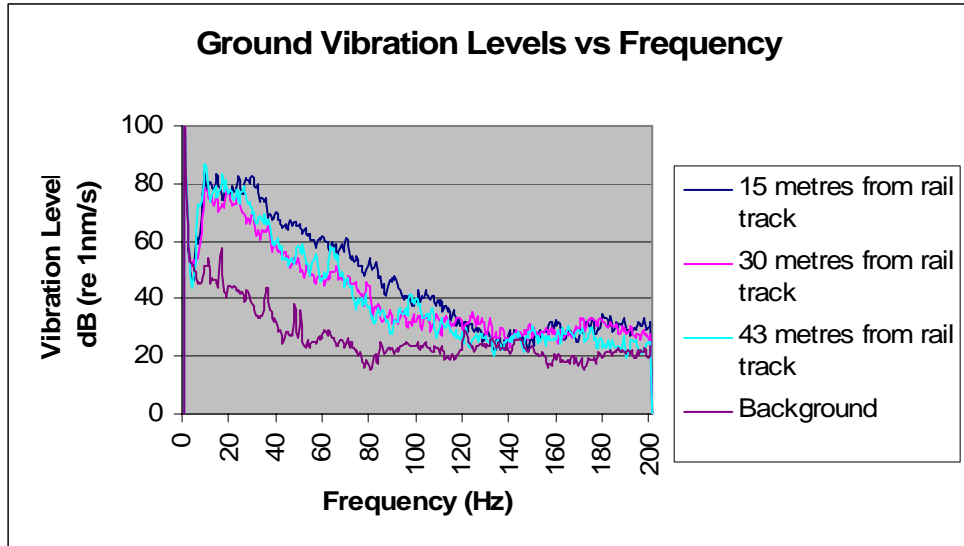


Figure 2

Figure 2 Ground Vibration Levels for three suburban train pass-bys at 15, 30 and 43 metres from the train tracks. The train speeds were approximately 60 Kph.

4.1.2 Ground Vibration Level in the Hospital Grounds.

Figure 3 below presents the typical ambient ground vibration levels outside the Clinical Building and the typical floor vibration levels on the office floor adjoining the MRI Unit.

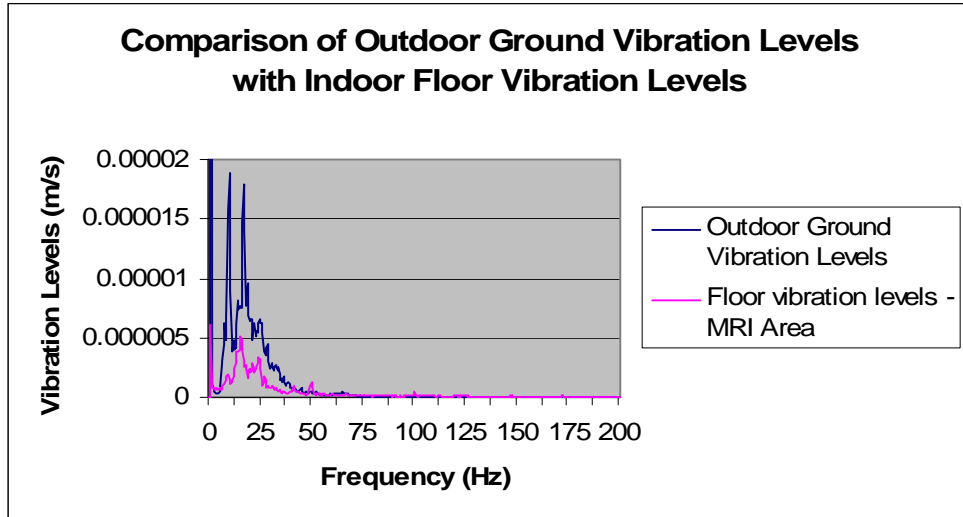


Figure 3

Figure 3 Typical ambient ground vibration level recorded outside the Clinical Building in comparison with the floor vibration levels next to the MRI Unit.

4.1.3 Floor Vibration Levels.

The floor vibration levels were monitored over a 20 hour period at 1 minute intervals in the MRI offices and in the Nurse Unit Manager’s Office directly adjacent to the operating theatres in the Clinical Building (Designated Building 07).

4.1.3.1 MRI Office.

Figure 4 presents a comparison of the typical floor vibration levels measured in the office adjoining the MRI Unit at various times throughout the data recording period.

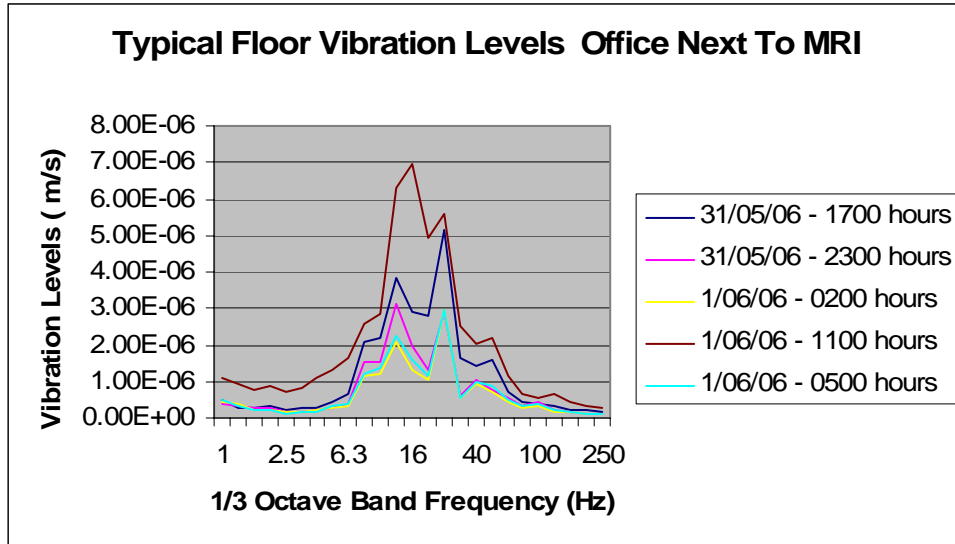


Figure 4 Typical floor vibration levels measured on the office floor directly adjacent to the MRI Unit over an 18 hour period.

4.1.3.1.1 Floor Response Due to Footfall and Impact Test.

Figure 5 presents vibration spectra of the natural frequency response of the concrete slab due to footfall and the slab response to an impact test in the office space directly beside the MRI Unit.

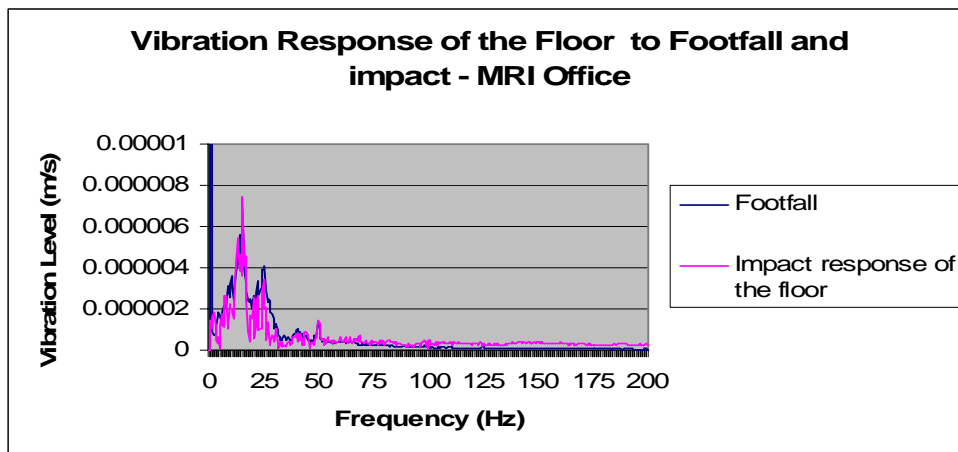


Figure 5 The concrete slab floor response to footfall and due to an impact test in the office space adjoining the MRI Unit.

4.1.3.2 Next to the Operating Theatres.

Figure 6 presents a comparison of the typical floor vibration levels measured in the Nurse Unit Manager’s Office at various times throughout the data recording period.

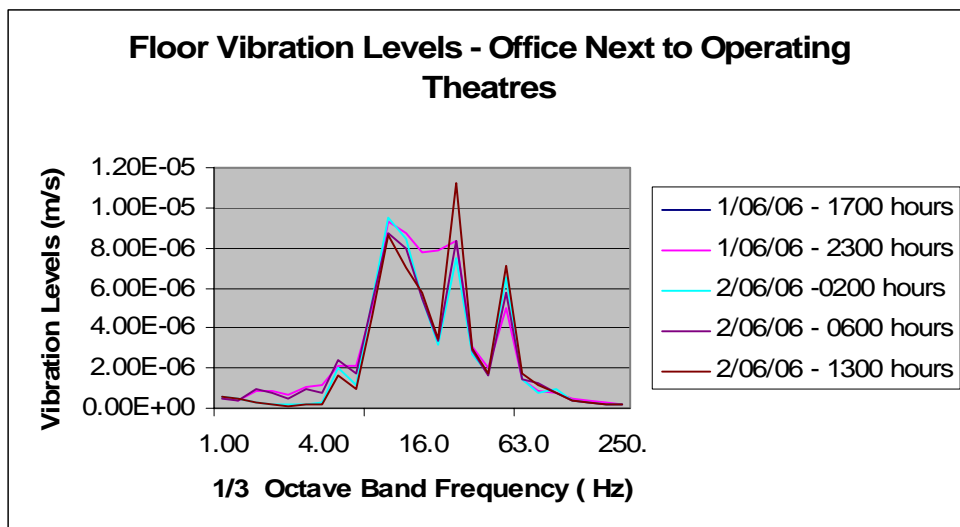


Figure 6. The typical floor vibration levels measured on the office floor directly adjacent to the Operating Theatres over a 20 hour period.

4.2 Sound Pressure Levels.

Indoor and outdoor A Weighted Sound Pressure Level measurements were performed in the Liverpool Hospital complex to determine typical ambient noise levels. Sound pressure level measurements were performed in areas perceived as areas likely to be affected by the proposed construction program.

4.2.1 Sound Pressure Levels - Train Pass By.

Table 1 below presents the sound pressure levels measured at a distance of 15 metres from the railway tracks.

Table 1 Sound Pressure Levels due to Train Passbys

Train Configuration	Estimated Train Speed (KPH)	A Weighted Sound Pressure Level dBA (re 2 x 10 ⁻⁵ Pa)		
		L _{A10}	L _{AMax}	SEL
8 car - Goninan -up	55 - 60	81.5	82.5	87
8 car – Goninan- down	25 - 30	68.5	78.5	79
8 car - Tangara -up	40 - 45	74	75	82
6 car – Goninan- down	55 - 60	74.5	92*	85
8 car - Tangara -up	20 -25	66.5	68.5	77
8 car - Goninan -up	55 - 60	81.5	84.5	88
8 car - Goninan -up	50 - 55	79	80	80.5
8 car - Tangara -down	40 - 45	76	77.5	85
6 car – Goninan- up	55 - 60	78	79	85
8 car - Goninan –up/ 8 car - Tangara -down	40 – 45 35 - 40	76.5	82	87
6 car – Goninan- down	40 - 45	73	75	81
Bells at Level Crossing only	-	62	72	-

* Train horn

4.2.2 Ambient Sound Pressure Levels in the Hospital Grounds.

Table 2 below presents the typical A weighted sound pressure levels measured in the hospital grounds. Noise levels measurements were performed over a 15 minute measurement period.

Noise level measurements were not performed with a helicopter in operation as the air ambulance was not required during the duration of the noise and vibration survey.

Table 2 Sound Pressure Levels in the hospital grounds

Measurement Location	A Weighted Sound Pressure Level dBA (re 2×10^{-5} Pa)			
	L_{A90}	L_{A10}	$L_{A\text{Max}}$	$L_{A\text{eq}}$
Grassed Area directly opposite Mental Health Building (Proposed demolition/ construction area)	48.5	53	69	52
Grassed Area directly opposite Brain Injury Building (between Brain Injury Building – Dunbier Building)	36.5	52	73	50.5
Helipad Apron	57	59.5	80	59

4.2.3 Ambient Internal Sound Pressure Levels.

Table 3 below presents the typical A-weighted sound pressure levels measured in various areas of the hospital buildings that may be affected by noise generated by the proposed construction work.

Table 3 Sound Pressure Levels at various locations inside the hospital buildings

Measurement Location	A Weighted Sound Pressure Level dBA (re 2 x 10 ⁻⁵ Pa)			
	L _{A90}	L _{A10}	L _{AMax}	L _{Aeq}
Clinical Building				
Beside ICU Entrance – East Façade	45	48.5	69.5	48.5
Foyer next to operating theatres 2 nd floor	52	62.5	77.5	59.5
South East Façade – 5 th Floor	44.5	57	74	54
ICU Ward Unattended Logging				
Day	44	58	74	59.5
Evening	45.5	55	73	58.5
Night	42.5	47	68	54
MRI Office	53	59	84	59
Mental Health Building				
Foyer close to the Southern Façade of Building (near proposed construction site)	46	59	75	56.5
Brain Injury Building				
In office of Programme Co-ordinator	32	35	-	39

5. Discussion.

The existing ground vibration, structural vibration and the indoor and outdoor acoustic environment at various locations in and around the Liverpool Hospital has been documented to establish a base line of the existing ambient conditions. These baselines form the basis of noise and vibration limits or acceptability criteria for the following circumstances:-

- Existing Building configurations.
- Proposed construction works and the possible impact on the existing building environments.
- For the proposed buildings where the impact of train ‘pass by’ or helicopter ambulance landing or takeoff from the Development Zone A Building will need to be considered.

5.1 Existing Vibration Levels

5.1.1 Train Pass-by Vibration Levels

Vibration level measurements were conducted to determine the typical ground vibration levels generated by train pass bys while structural vibration levels were measured in vibration sensitive areas to determine the typical ambient vibration levels.

Several sites were assessed to determine vibration sensitive areas that may be adversely impacted by increased ground vibration levels due to construction work and increased rail traffic from the proposed development of a third rail line.

5.1.1.1 Ambient Ground Vibration

Ground vibration levels measurements were performed between the Engineering Building and the Drug Health Building. This measurement position was selected as it gave good access to the grassed areas (allowing a stake to be driven into the ground whereas the other areas were asphalt or concrete covered) It was also noted that the measurement position was in a direct line from the railway track to the Clinical Building.

Ground vibration level measurements were performed during 19 train pass bys. The train configurations consisted of suburban 8 and 6 car sets and two freight train pass-bys.

The train speeds ranged from approximately 60 kph to 5 – 10 kph. This was due to the level crossing located approximately 80 metres from the measurement site and the Liverpool Railway Station which was located another 50 – 60 metres further on from the measurement site. The freight trains were travelling at reduced speed close to the measurement position and did not

generate high vibration levels because of the reduced train speed. The levels generated by the freight trains were of the same order of magnitude as the ground vibration levels generated by the suburban trains.

The rail track was a continuously welded configuration with no discontinuities, reducing wheel /rail impacts, hence reducing the transfer of vibration into the ground as well as the overall noise levels that would normally be generated by a discontinuity in the rail.

From the measured data, it is difficult to obtain a definitive relationship of attenuation of ground vibration levels with distance for the following reasons:-

- Measurements were performed with one accelerometer only (sensitivity of 10 v/g) due to the low magnitude of the vibration levels at the 15, 30 and 43 metre positions (note that accelerometers with this sensitivity are not easy to obtain). Thus simultaneous measurements were not possible and as the magnitude of the variation in level between measurements was large, a conclusion could not be definitive.
- Direct correlation could not be performed due to variability in train speeds and the wheel condition of the individual train configurations.

Figure 1 above presents the typical ground vibrations generated by the train pass-bys at the 3 measurement distances. It can be noted there is a significant decrease in the overall ground vibration level of 35 dB (re 1nm/sec) as frequency increases from 30 Hz to 100 Hz for all of the train pass-by measurements. These findings agree with theory which suggests that high frequencies attenuate at a greater rate than lower frequencies in soil.

To derive an indication of the attenuation of the ground vibration with distance, the ground vibration levels of three discrete suburban trains travelling at approximately 60 Kph on the 'up' track was plotted in relation to the three measurement positions. Figure 2 presents the vibration levels at the 3 measurement positions of 15, 30 and 43 metres. From the graph it can be determined that there is no significant attenuation with distance in the frequency range 0 – 30 Hz.. In the 30 Hz to 100 Hz frequency range, it can be noted that an 8 – 10 dB attenuation is achieved in moving from 15 metre to 30 metres, however, there is very little attenuation between the 30 metre and 43 metre measurement locations. This result is most likely due to the fact that the ground vibration measurements were not performed simultaneously but serially on discrete train pass-bys. In 120 Hz -200 Hz frequency range, the ground vibration levels at all 3 measurement positions fall within the range of the background vibration levels.

Ground vibrations are composed of a surface wave (Rayleigh wave), a shear wave (S – wave) and a compression wave (P-wave). The surface wave has horizontal and vertical components. The surface wave decays due to ground damping much more slowly with distance than the shear and compression waves. Material damping in soil is a function of many parameters including soil type, moisture content and temperature. For example clays tend to exhibit higher damping characteristics than sandy soils and wet sand attenuates less than dry sand because of the water between the sand particles. Typical attenuation values reported in literature (Nelson 1987 p16/8) present an attenuation rate of 2.7 dB per wave length for Rayleigh wave propagation in sand.

5.1.1.2 Building Structure Vibration levels

After discussion with various personnel at the hospital, vibration critical areas, that is, areas where the operating performance of equipment or processes could be severely compromised by structural vibration, were determined. Two critical areas were nominated for investigation. Both these areas were located in the Clinical Building. These areas were:

- The MRI Area
- The Operating Theatres.

Other areas were investigated such as the Brain Injury Building (Area 12) but it was determined, due to the nature of rehabilitation work to be performed in these areas, that the structural vibration levels would not be so significant as to have an impact on work performances or processes.

Figure 3 presents the typical ground vibration levels measured in the courtyard of the Clinical Building and the typical structural vibration levels measured in the office area next to the MRI unit. It can be seen that the vibration levels measured on the floor of the building are significantly lower than the ground vibration levels due to a ‘coupling loss’.

Long term vibration monitoring was performed at the two nominated vibration critical areas.

5.1.1.2.1 MRI Unit

Figure 4 presents representative floor vibration levels measured at discrete times throughout the day and night time in the office adjacent to the MRI Unit. The MRI is not operational at night time and pedestrian traffic is minimal. The floor vibration levels in this area at night were significantly lower in magnitude than in the day time when there is significant pedestrian traffic.

Footfall seems to be the dominant source of floor vibration in the MRI area. Vibration measurements were performed with a female Radiographer wearing ‘low heel’ shoes walking

around the office area of the MRI Unit. Figure 5 presents the typical floor vibration levels and frequency content due to the ‘footfall’ of the female radiographer simulating the pedestrian traffic. Figure 5 also presents the frequency response of the concrete floor during an impact test. Both the impact test and the footfall spectra show the floor response or natural frequency of the slab floor is 13 Hz. The vibration levels measured in the office beside MRI unit are significantly lower than the vibration levels presented for perceptibility in critical areas in hospitals as shown in BS 6472 :1992 titled ‘Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz)’. Indeed, they were lower by a factor of approximately 14 times.

5.1.1.2.2 Operating Theatres

Figure 6 presents representative floor vibration levels measured at discrete times throughout the day and night time in the office adjacent to the Operating Theatres in the Clinical Building. The vibration levels measured in the Nurse Unit Managers office beside the Operating Theatres are significantly lower than the acceptable vibration levels for perceptibility in critical areas of hospitals as shown in BS 6472 :1992 titled ‘Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz)’. Indeed, they were lower by a factor of approximately 10 times.

5.1.2 Ambient Sound Pressure Levels

‘A’ weighted sound pressure levels were measured in various areas of the hospital grounds and in various buildings to determine the typical ambient noise levels in the existing hospital facility.

5.1.2.1 Outdoor Ambient Sound Pressure Levels

Table 1 presents outdoor noise level measurements performed at the fence line approximately 15 metres from the railway track on the Eastern Boundary of the Hospital grounds for a range of typical train pass-bys. Typical maximum sound pressure levels were in the range 80 – 85 dBA at 15 metres. The sound pressure levels generated by train pass-bys would not impact on the existing internal noise levels in the Brain Injury, Clinical and Mental Health Buildings due to the Transmission Loss of the building facades, the distance from the train line and shielding by existing buildings.

Outdoor ambient noise level measurements were also conducted directly outside the Brain Injury Building and in the grassed area opposite the Mental Health Building (Building 30) and the B Wing (Building 15). Ambient sound pressure level measurements were also performed on the helicopter landing apron on top of the Clinical Building. From Table 2 it can be seen that the background sound pressure levels (L_{A90}) outside the Brain Injury Building were approximately 36.5 dBA while in front of the Mental Health Building the ambient sound pressure levels were 56.5 dBA. The latter background sound pressure levels were dominated by air conditioning plant noise on the

Mental Health Building and at the CCORE building. The ambient sound pressure levels measured at the apron of the helicopter pad were dominated by both air conditioning plant noise located on the roof top of the Clinical Building as well as general background noise from the local community such as road traffic.

5.1.2.2 Indoor Sound Pressure Levels

Table 3 presents the typical ambient sound pressure levels measured indoors in the Clinical, Mental Health and Brain Injury Buildings. Typical sound pressure levels for the Clinical Building ranged from 42.5 dBA (ICU Ward night time) to 53 dBA(MRI office day time). The ambient indoor noise levels in these areas were dominated by people generated noise. e.g. people talking or moving equipment such as trolleys. Train pass-bys were not audible in any of these areas.

Indoor ambient sound pressure level measurements in the Mental Health Building were again dominated by people communicating. Indoor ambient sound pressure level measurements were also conducted in the office of the Programme Co-ordinator. The office was vacant and the door closed so that the typical ambient sound pressure level without the impact of people talking close by could be measured.

Australian Standard/ New Zealand Standard AS/NZS 2107 – 2000 titled ‘ Acoustics- Recommended Design Sound Levels And Reverberation Times for Building Interiors’.

presents the recommended design sound levels (L_{Aeq}) for a range of areas in Health Buildings.

The recommended design sound levels are presented in Table 4 below and are based on the assumption of an unoccupied space and that there is no noise due to people communicating:-

Table 4 Indoor recommended design sound levels for Health buildings

Type of Occupancy/ Activity	Recommended Design Sound Level L_{Aeq} dBA	
	Satisfactory	Maximum
Wards	35	40
Corridors and lobby spaces	40	50
Foyers	40	50
Private Office	35	40



Based on our measurements, it is likely that the measured locations comply with the requirement of the Standard.

5.2 Proposed Building Construction Works

The proposed demolition and construction works will be performed in close proximity to the Clinical and Mental Health Buildings (See **Appendix A** for works locations).

It is believed that the construction work will incorporate numerous pieces of equipment which may generate significant ground vibration levels and high sound pressure levels. Due to these sources being in close proximity to the Clinical and Mental Health Buildings, the indoor ambient building vibration levels and sound pressure levels may be significantly impacted.

5.2.1 Vibration

Ground vibrations generated by heavy construction or operations such as piling may have significant effect on equipment, patients and operations within the Clinical and Mental Health Buildings. Other buildings may be affected due increased road traffic or heavy vehicle pass-bys.

Two areas in the Clinical Building have been identified as vibration and noise critical. High levels of concentration are required during eye surgery or brain surgery and any sudden high impact noise and vibration levels would be of considerable concern. The MRI unit also requires extremely low floor vibration levels for successful operation.

The effects of structural vibration can be categorized as follows:-

- Human Comfort
- Effect on operational equipment or operations
- Building integrity

Ground vibration can cause structure borne noise which would also have an influence on human comfort. The human comfort criteria for vibration levels are much more stringent than that for building integrity due to vibration impacts.

5.2.1.1 Human Comfort

Vibration from a source is usually measured in three axial planes (longitudinal, lateral and vertical planes). Human comfort criteria may vary depending on the mode of transmission (continuous or intermittent) and is also frequency dependent.

British Standard BS 6472 - 1992 titled 'Evaluation of Human Exposure to Vibration in Buildings' presents guidance criteria for satisfactory magnitudes of building vibration with respect to human response. For vibration critical areas such as the Operating Theatres and the MRI unit located in the Clinical Building, BS 6472 - 1992 sets a building vibration multiplying factor of 1 which relates to curve 1 for Figures 5 and 7 in BS 6472 – 1992 for both intermittent and continuous ground vibration operations. If during construction, the requirements presented in BS 6472-1992 are met, then there should not be any adverse comments, sensations or complaints.

Similarly, for the Mental Health, Brain Injury and the Ron Dunbier Buildings, the multiplying factor is 1.4 to 2 for the residential building (Ron Dunbier) and the multiplying factor is 4 for the office areas such as in the Mental Health and Brain Injury Buildings. These multiplying factors relate to curves titled 1.4, 2 and 4 on Figures 5 and 7 of BS 6472 – 1992. If during construction, the requirements presented in BS 6472-1992 are met, then there should not be any adverse comments, sensations or complaints.

To achieve the recommended building vibration levels, consideration of the proposed demolition and construction methods and equipment to be used is required prior to the instigation of the project. Operations such as piling need to be assessed prior to and during the operation to ensure that the nearby vibration sensitive areas do not receive excessive vibration levels.

5.2.1.2 Operational Equipment

The most vibration sensitive piece of operating equipment in the hospital is the MRI machine. Vibration measurements adjacent to the existing MRI machine show that vibration levels are dominated by foot fall on floor slabs. More distant sources of environmental vibration such as from train pass bys are not significant. This is also expected to be the case for the new MRI installation. The new MRI installation should include an isolated plinth similar to the existing machine to attenuate vibration from foot fall within the hospital.

Strategic planning should be conducted with respect to traffic flow to and from the construction site. At present, vehicles enter the hospital site from Campbell Street and exit at Elizabeth Street.

Access to the construction site may be beneficial through a dedicated gateway on Elizabeth St. to limit vehicle pass-by vibration impact at the various building sites rather than using the existing traffic circuit within the Liverpool Hospital site. Heavy equipment movement should be limited and should be located further away from the Mental Health Building and Brain Injury Building reducing the vibration impact.

5.2.1.3 Building Structural Integrity

Vibration resulting from construction activities for protecting buildings against vibration damage should comply with the requirements of German Standard DIN 4150: Part 3- 1999. The Standard recommends vibration levels (Peak Particle Velocity (mm/s)) as measured at the foundation of the building and are summarised in Table 5 below :-

Table 5 Vibration limits to protect buildings from damage

Line	Type of Structure	Guideline Values for Velocity, V_i (mm/s)			
		Vibration at the Foundation at a frequency of			Vibration at Horizontal Plane of highest Floor at all Frequencies
		1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz	
1	Buildings used for commercial purposes, industrial buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and /or use	5	5 to 15	15 to 20	15
3	Structures that, because of their sensitivity to vibration, do not correspond to those listed in lines 1 and 2 and are of great intrinsic value (eg Buildings that are under a preservation order)	3	8 to 10	8 to 10	8
* for frequencies above 100 Hz, at least the values specified in this column shall be applied					

The vibration levels presented in this Standard exceed the Human Comfort criteria presented in Sections 5.2.1.1 and 5.2.1.2 above. Therefore, the human comfort criteria should be the over riding criteria for the any vibration sensitive buildings on site.

5.2.2 Sound Pressure Levels

5.2.2.1 Construction Noise Levels

For extended construction periods, the NSW Department of Environmental Conservation (DEC) provides guidelines for construction noise emissions during normal operational hours. Table 6 below details the Department of Environmental Conservation noise level goals for various construction periods in terms of the L_{A10} (the noise level exceeded for 10% of the 15 minute time interval - this metric is commonly referred to as the average maximum level).

Table 6 DEC guidelines for construction noise

No.	Duration of Works	Department of Environmental Conservation L_{A10} Guidelines
1	Construction Period of 4 weeks and under	The L_{A10} sound pressure levels measured over a period of not less than 15 minutes when the construction site is in operation must not exceed the background level (L_{A90}) by more than 20 dBA
2	Construction period greater than 4 weeks and not exceeding 26 weeks	The L_{A10} sound pressure levels measured over a period of not less than 15 minutes when the construction site is in operation must not exceed the background level (L_{A90}) by more than 10 dBA
3	Construction period greater than 26 weeks	The EPA does not provide noise control guidelines for construction periods greater than 26 weeks duration, however, it is generally accepted that provided the L_{A10} sound pressure levels from the construction area do not exceed a level of 5 dBA above background, then adverse (intrusive) noise impacts are not likely to be experienced at the nearest sensitive receptor locations.

Restrictions are also placed on the hours of construction to ensure the acoustic amenity of the closest residences is protected. These restrictions are as follows:

Work can proceed Monday to Friday: 7 am to 6 pm and on Saturday: 8 am to 1 pm. However, No audible construction work is to take place on Sundays or public holidays.

In NSW special construction licences are required for works outside of these hours and are issued on a case by case basis by the Department of Environmental Conservation. It is recognized that while the noise emission levels presented in Table 6 are target levels, in practice these levels may be exceeded at the nearest residences for short periods due to nature of construction activities. At all stages of works, these levels should remain the target levels and be controlled by regular monitoring.

Although these noise criteria are proposed for construction works in residential areas, the criteria could still be applied in principle to the construction site in the Liverpool Hospital site as the construction noise could have a significant impact on the ambient noise in wards located on the Eastern / South Eastern facades of the Clinical Building.



It has been envisaged that construction work would be performed during normal working hours only and not during the night time when patients would be impacted upon.

From the background noise level measurements (L_{A90}) performed at two locations within the hospital grounds and using the construction noise criteria presented by the NSW DEC, an indication of the maximum allowable noise levels can be determined. The existing background sound pressure level (L_{A90}) at the proposed demolition and construction site was determined to be 48.5 dBA. Using the criteria presented by DEC, the allowable L_{A10} sound pressure level at the construction site would be a maximum of 58.5 dBA. These numbers are not realistic for a construction site where numerous pieces of equipment will be located within a relatively confined area.

Another approach to an appropriate noise criterion is to consider the existing indoor background noise levels inside, say the Clinical Building where indoor noise levels were approximately 45 dBA. Assuming a transmission loss of the existing building façade of say 20 – 25 dBA and an allowance for distance from the noise sources to the receivers of approximately 30 metres, the overall allowable construction noise level would be approximately 90 dBA at the construction site. This is more realistic.

Table 7 below presents the typical sound power levels of construction equipment likely to be used on the construction site.

Table 7 Sound Power Levels of Construction Equipment

Construction Equipment Configuration	Typical Sound Power Level (dBA)
Excavator	112
Concrete truck	115
Concrete pump	102
concrete vibrator	108
Crane	115
Truck	108
Bored Piling Rig	119
Back Hoe	104
Tracked Dozer	115
Land fill compactor	110
Compressor	100



To determine the typical sound pressure levels that may be generated during the construction is difficult as different pieces of equipment may be operating intermittently at various times. However, an indication of the typical noise levels that may be generated at the construction site can be obtained based on the following assumptions:

- 1 excavator operating
- 2 trucks on site
- 1 tracked dozer operating
- 1 piling rig operating
- 1 compressor operating
- Power tools e.g. saws / drills / etc

Calculated typical sound pressure level at a distance of approximately 30 metres would be in the order of 94 dBA. This indicative level will change as equipment is located closer or further away from noise sensitive receiver points. Administrative procedures need to be incorporated to ensure that the construction equipment is used during day time only and is operated for the minimum amount of time possible.

5.3 Impacts on the New Buildings

The proposed new buildings are closer to the existing railway track and therefore ground vibration and noise from train pass-bys may have an impact on the indoor ambient environment. The proposed building facade for development zone A is located approximately 50 – 60 metres away from the railway line while the building development zone F and Engineering Services are to be located approximately 25 -30 metres from the rail line.

From the RailCorp report titled 'Signal Engineering – Operational Impact of SSFL and Liverpool Clearways Project on Liverpool Hospital Level Crossing' dated March 2006, it can be seen that it is proposed that the Southern Sydney Freight Line (SSFL) will build a new railway track on the Eastern side of the existing rail tracks in 2008. The impact of this is that it will reduce the distance between the proposed Engineering Services Building and the SSFL track to approximately 20 – 25 metres. It has been assumed the track construction method is similar to the existing track construction, that is, it will have rails on timber sleepers on ballast and continuous welded track.

A fourth track incorporating a 'Turnback' road is planned to be constructed in 2011. With the addition of this track, it is assumed that the Up line will be moved closer to the proposed buildings Development zone A and development zone F by approximately 5 metres.

5.3.1 Ground Vibration

From the ground vibration measurements performed at the western boundary of the Liverpool Hospital for train pass-bys, it was determined that low magnitude ground vibration levels were generated and that, currently, there is no impact in vibration sensitive areas of the hospital.

Ground vibration levels for the proposed rail track configuration and the increased train operating speeds have been predicted based on the following operational parameters extracted from the RailCorp report:

- Commuter train pass by speed to be 80 KPH on the 'DOWN' and 100 KPH on the 'UP'.
- Diesel Passenger trains 100 KPH (SSFL Environmental Assessment Report)
- Number of commuter train pass bys are approximately 20 per hour.
- SSFL freight train speed to be 80 KPH
- Number of freight train pass bys to be approximately 1 – 3 per hour.
- The fourth rail track is a 'turnback' between the UP and DOWN tracks with 'cross over' points. Location of the 'cross over' points has not been defined. It has been assumed that these points will be located a distance away from the proposed buildings.

Using the ground vibration data measured during the survey at a distance of 30 metres (existing track and train speed configuration), the predicted ground vibration levels due to the increased train speed and using a worse case scenario of train pass-bys occurring on three tracks simultaneously at the maximum train speeds have been calculated. The fourth track has a 'turnback' and it is assumed the train speeds will therefore be significantly slower on this track than the other three tracks. It will therefore will not have significant impact on the overall noise and vibration levels..

Figure 7 presents the predicted increase in ground vibration levels at a distance of 30 metres for the worse case scenario of two trains using the tracks at a maximum train speed of 100 KPH and 80 KPH and the SSFL operating at 80 KPH.

In calculating the predicted ground vibration levels, it has been assumed that:

- The track configuration is of the same construction and ballast configuration as for the existing track configuration.
- All rail lines will be of continuous welded track. There are to be no discontinuities in the track to cause wheel / rail impacts.
- Train wheels are of a similar condition as the existing i.e. wheel flats, spalling etc

- The proposed ‘cross over’ points are to be located a distance away from the proposed buildings.

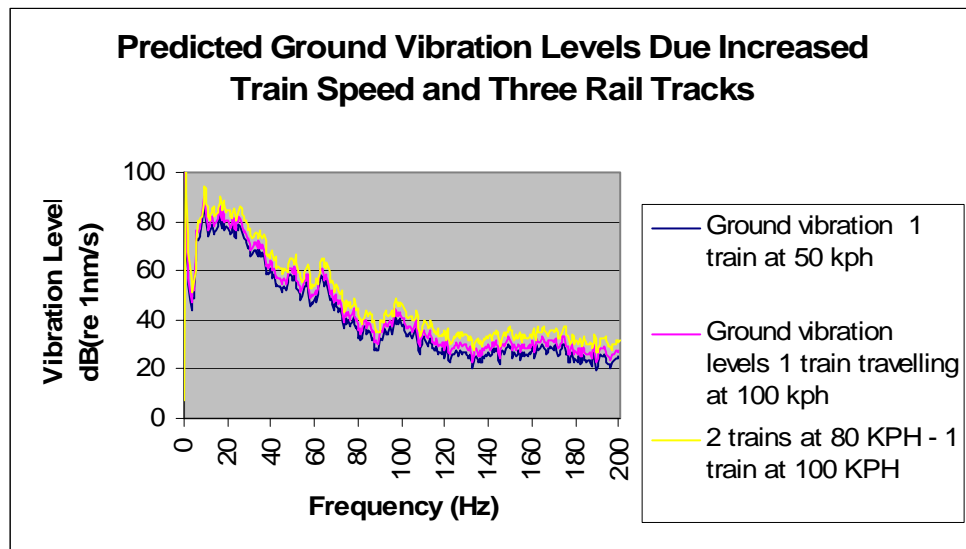


Figure 7. Predicted ground vibration levels at 30 metres from the rail tracks with three trains using the tracks travelling at 80 /100 KPH

Assuming there is no amplification of ground vibration in the building structure, compliance with the requirements for the MRI unit and other vibration sensitive instrumentation operating areas and surgery areas in the proposed buildings should occur based on the criteria for human comfort as per Curve 1 of Figures 5 and 7 in BS 6472 : 1992.

If the ‘cross over’ points are to be located in the near vicinity of the proposed buildings, a ground vibration survey would need to be performed to determine the typical vibration levels generated due to trains impacting on the points at speeds of 80 /100 KPH and these vibration levels then would need to be related to the criteria for the sensitive occupancies in the buildings.

The predicted ground vibration levels generated by the increased rail traffic and train speeds will not affect the internal environment of the existing buildings.

5.3.2 External Noise Sources

5.3.2.1 Train Pass Bys

The noise assessment below is based on the maximum noise levels generated due to the train pass-bys. If not controlled, the impact of the train pass bys may affect the concentration levels of surgeons during a delicate operation or may have the effect of startling patients in wards.

Australian Standard/ New Zealand Standard AS/NZS 2107 – 2000 titled ‘Acoustics- Recommended Design Sound Levels and Reverberation Times for Building Interiors’ (see Table 4 for an indication of the recommended Design Sound Levels) presents the recommended internal design sound levels for various areas of occupancy within a hospital. These design criteria are for a quasi steady state continuous noise sources such as air conditioning equipment and distant road traffic. They do not apply to situations where discreet independent rapid noise impacts such as train pass bys occur. Therefore the maximum noise level has been chosen as the basis for noise reduction requirements

Australian Standard AS 2021 – 2000 titled ‘Acoustics – Aircraft Noise Intrusion Building Siting and Construction’ may be used to provide guidance for acceptable noise levels for various building occupancies. This Standard presents the maximum recommended noise level for a ward or a Theatre as 50 dBA. An aircraft flyover may be of a longer duration than a suburban train pass by, but it is likely to be representative of a long freight train pass by.

5.3.2.2 Impact of Increased Train Speeds and Construction of SSFL Track on Existing Buildings.

The predicted noise levels at the outer facade of the Clinical building with the proposed increased train speeds and the SSFL train line constructed and in use would be in the order of $L_{A_{Max}}$ 68 - 73 dBA. These calculated noise levels have been based on the assumption that the intervening buildings are demolished in preparation for the construction works.

It is also proposed to demolish the Ron Dunbier Building and the Engineering buildings. These buildings at present act as ‘acoustic barriers’ for the Brain Injury Building and also provide some screening for the Mental Health Building. Removal of these buildings will have an impact on the acoustic environment in this area with typical sound pressure levels at the Eastern facades of the Mental Health and the Brain Injury buildings increasing to the order of $L_{A_{Max}}$ 63 - 68 dBA and 64 – 69 dBA, respectively. Assuming a transmission loss of 20 -25 dBA across the facade, the internal ambient noise levels in both buildings will still meet the requirements of Australian Standard/ New



Zealand Standard AS/NZS 2107 – 2000 and are below the recommended sound design levels of 55 dBA for a private office as recommended in AS 2021-2000.

5.3.2.3 Impact of Train Pass Bys on Proposed Hospital Buildings.

Due to the close proximity of the proposed Development Zone A & F buildings and the Engineering Services building to the railway tracks, the building facade construction has to be designed such that an acceptable internal acoustic environment is achieved in each case. Train pass by sound pressure levels were measured to be in the order of $L_{A_{Max}}$ 80 - 85 dBA at 15 metres at train speeds of approximately 50 - 60 KPH.

From Appendix A, it can be seen that the distances the proposed buildings are to be located from the proposed train lines would be in the order of 15 – 20 metres for Engineering Services and Development Zone F and 45 – 50 metres for Development Zone A. Typical $L_{A_{Max}}$ sound pressure levels at the external facades would be approximately 81 - 86 dBA and 75 – 80 dBA with the existing train track and train running configuration.

From the noise level measurements for the train pass bys in this survey, the predicted maximum noise levels generated due to the increased train speeds (80 / 100 KPH) and three train pass bys occurring simultaneously directly outside the hospital buildings would be approximately $L_{A_{Max}}$ 92 – 97 dBA at a distance of 15 metres.

Using data presented in the Southern Sydney Freight Line Environmental Assessment Report, Report No. 05032, the predicted sound pressure levels due to increased train speed, the number of train pass bys and the third running track, would be $L_{A_{max}}$ 97 dBA at 27 metres and a $L_{A_{eq}}$ 24hour 70.7 dBA (year 2008) and 73.6 dBA (year 2018). This latter noise level data is higher than would be indicated using SKM measurements and has therefore been used to provide a conservative assessment for planning purposes.

For the worst case scenario of three train pass bys occurring simultaneously and train speeds of 80 and 100 KPH, the predicted maximum noise level at each of the proposed building facades would be in the order of 97 – 102 dBA and 91 – 95 dBA respectively.

Using the recommended $L_{A_{Max}}$ sound design criteria presented in Table 3.3 of AS 2021, the building facades are required to achieve a noise reduction of approximately 42 – 47 dB for the Engineering Services Building ($L_{A_{Max}}$ 55 for offices) and Development Zone F, while Development Zone A ($L_{A_{Max}}$ 50 for an operating theatre) would require a noise reduction of 41 – 45



dB. This assumes that these acoustically sensitive spaces are located immediately on the most exposed facade of the buildings rather than internally.

To achieve a noise reduction of 45 – 47 dB across the building facades is extremely difficult. It is recommended that any acoustically sensitive uses be located internally in the building, rather than against the exposed facade.

If for some reason, this is not possible, then the use of acoustic barriers along the length of the Development Zone A on the western train reserve and along the Eastern boundary in front of the Engineering Services Building would need to be considered. The barriers would have to a minimum height of 4 metres and follow the building contours for a distance of more than 20 metres along the Southern boundary for each building. The barrier could achieve a noise reduction of approximately 13 dB for the lower floor levels on the multi storey building (Development Zone A). However, the floor levels that have direct line of sight of the trains will not have any direct benefit from the barriers. Detailed attention would therefore be required to determine acoustically acceptable external facades (glazing/wall/door) configurations for each of the upper level floors for the multi storey building.

The best option for achieving the noise criteria is to locate the operating theatres and MRI equipment away from Eastern and Southern facades of the proposed building. The general arrangement should be similar to the existing layout in the Clinical Building now in use. The internal design of the hospital needs to be closely scrutinized to ensure that noise sensitive areas such as the operating rooms and wards are orientated such that non sensitive uses such as foyers, corridors, cleaning areas are located between these areas and the Eastern / South Eastern outer facades of the proposed buildings.

5.3.2.4 Road Traffic

Road traffic along Elizabeth Street is limited due to the road ending at a dead end after the railway crossing. From inspection, the road traffic was dominated by employee traffic and visitors parking on the side of the street. Traffic along Goulburn Street was relatively light with traffic mainly travelling along Goulburn St. to access the hospital car parking area. Therefore, road traffic noise is not an issue.



5.3.2.5 Helicopter

During the noise and vibration survey, the helicopter landing platform was not used and therefore, no conclusions can be drawn with respect to design details for the situation with the existing helicopter in use.

At present, the helipad is located on the roof of the Clinical Building, however, it is proposed to relocate the helipad to the roof of Development Zone A Building. From the plans presented in Appendix A, it can be seen that the proposed Development Zone A Building and the Clinical Building have a common wall. Therefore, structural and/or acoustic excitation of the proposed building structure due to the helicopter landing or taking off may have impact on the vibration sensitive areas located in the Clinical Building. As long as similar structural/isolation measures are incorporated into the proposed building structure, no vibration or structure-borne noise impact should be observed.

Given the close proximity of the proposed relocated helicopter landing pad to the existing Clinical Building and Development Zone A, air-borne noise mitigation measures will need to be considered in the detailed design of the building envelopes.

6. Construction Mitigation Measures

6.1 Vibration

Due to the construction works being performed in close proximity to vibration critical areas, it is strongly recommended that appropriate precautions be taken to limit or avoid potential vibration impacts. If the human perception criteria presented in BS 6472: 1992 are exceeded, then alternative methods of construction will need to be investigated to complete the works. If an alternative method is not available, negotiated arrangements will need to be employed to allow personnel in vibration critical areas to perform their normal operating duties.

6.2 Noise

Long term environmental noise surveys would be required to determine whether noise levels during the demolition and construction works met criteria for construction noise. Periodical attended noise level measurements would allow the determination of any significant noise sources that may impact on the indoor acoustic environments in the adjacent hospital buildings. If the noise levels generated by the construction works do impact on the acoustic indoor environments of the adjacent buildings, noise control measures will need to be incorporated for the significant noise sources or, alternatively, administration of work practices will need to be considered.

Both the vibration and acoustic surveys should be performed by a recognized independent qualified acoustic consultancy.



7. Conclusion

Sinclair Knight Merz has undertaken an assessment of the existing ambient noise and vibration levels at several locations both indoor and outdoor of various hospital buildings in the Liverpool Hospital complex. This assessment characterised existing ground vibration levels generated at the hospital boundary due to train pass-bys and structural building vibration levels in vibration critical areas. Indoor/ outdoor environmental noise levels were also documented.

Based on the results obtained, it is unlikely that vibration due to train pass-bys will be an issue at the new proposed buildings. However, noise will be a problem unless the noise sensitive uses in the hospital are located internally in their respective buildings. Alternatively, noise mitigation measures such as specially designed building facades and/or noise barriers will be required.

Noise and vibration during construction is likely to be an issue with respect to the existing buildings and measures to mitigate these impacts will need to be considered prior to commencing construction. Guidance on an appropriate construction noise limit is contained in this report.

Noise due to the location of the helicopter landing pad on the top of the new building in Development Zone A will require acoustically designed building facades on nearby buildings to ensure that noise sensitive occupancies are not adversely affected.

Appendix A Proposed Construction Details for the Liverpool Hospital.



SINCLAIR KNIGHT MERZ