



Railway Ground-Borne Noise in Terrace Houses: A Case Study

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Abstract - Ground-borne noise impact assessments often concentrate on the front room of affected properties and assume that noise levels are lower elsewhere. This paper reports on a case study that examined this assumption, exploring how ground-borne noise and vibration varied throughout a two-storey terrace house above a rail tunnel in Sydney. Simultaneous measurements of noise and vibration were recorded in front and rear rooms, on both the ground and first floors, during train passes. An additional measurement was recorded on the ground in front of the house to allow coupling loss to be determined. This paper presents the ground-borne noise and vibration levels throughout the house, examines the effectiveness of the common vibration-to-noise estimation method, and compares measured noise levels with those estimated using the popular Federal Transit Authority (FTA) method. The results may be used to inform future ground-borne noise assessments for underground railways.

1 INTRODUCTION

1.1 Background and aim

Ground-borne noise is commonly associated with trains in tunnels in urban areas (Thompson, 2024), where the tunnel completely blocks the airborne noise transmission path. Ground-borne is less commonly associated with surface railways, as reflected by the following commentary:

“In some rare instances, ground borne noise may be an issue for noise sensitive locations adjacent to surface or elevated track (ie. not just track in tunnel locations). These instances are uncommon, are not easily predicted, and will need to be assessed and managed on an individual basis, with the assistance of an acoustic consultant.” (NSW Department of Planning, 2008)

Ground-borne noise is therefore usually assessed in circumstances where railways are underground, or in specific situations for surface railways where the line-of-sight between the railway and the noise-sensitive receiver is blocked, by either a noise barrier (to address airborne noise concerns) or other natural barrier like a cutting.

It is also acknowledged that “groundborne noise may be an issue in habitable rooms which are shielded from airborne noise from the railway. Examples are rooms that are not facing the railway” (NSW Department of Planning, 2008). In practice however, the impacts on rooms that are not facing the railway are rarely assessed. The Parramatta Light Rail Stage 1 Operational Noise and Vibration Review (Renzo Tonin & Associates, 2022) provides an example of common practice for assessing ground-borne noise from light rail operations with residential dwellings in close proximity:

- Ground-borne noise levels are predicted for the worst-case ground floor location (i.e the room facing the railway).
- Where exceedances of the ground-borne noise levels are predicted, the internal airborne noise level predictions are reviewed. This is for policy reasons that are discussed further in the following section.

- Where the ground-borne noise levels are predicted to exceed both the ground-borne noise trigger level and the internal airborne noise level, additional mitigation measures are considered.

This assessment methodology relies on an implicit assumption that ground-borne noise will attenuate quickly within the building (i.e at least as quickly as it will attenuate through the ground), such that the ground-borne noise levels will be significantly lower than either the ground-borne noise trigger levels or airborne noise impacts in the rooms that are not facing the railway. This assumption is intuitive and supported by the following commentary:

“Usually, the vibration caused by train operations propagates upward through vertical load-bearing structures, such as structural columns. Since medium- and high-frequency vibration waves can effectively attenuate in the floor, their influence is limited to a short distance from the junction of the vertical load-bearing structure and the floor. Consequently, vibrations have a minimal impact on the mutual propagation of each vertical load-bearing structure. Thus, the propagation of vibration in a building can be considered upward propagation along a single vertical bearing structure with the attached floor, and the vibration of the floor is the sum of the vibration energy carried by each vertical bearing structure.” (He & Tao, 2024)

There is however, to the authors knowledge, no empirical data available describing how rail vibration attenuates with distance through buildings, and how efficiently it propagates relative to the ground. It may be possible to evaluate this through detailed modelling such as the use of finite elements, but this is usually impractical and cost-prohibitive in the context of a large infrastructure project, with potentially many affected receivers of varying structure types. Since detailed drawings are rarely available, particularly in the context of Sydney’s traditional terrace houses, such modelling would also require measurements to verify assumptions, which would ultimately defeat the purpose.

There are numerous sources of literature available that provide frequency-dependent transfer functions based on empirical data describing the change in vibration levels between the soil and the foundation caused by the change in impedance between the two mediums (more commonly known as ‘coupling loss’), the amplification of vibration within buildings caused by suspended slabs, how vibration changes as it transfers through columns to higher levels of the building (more commonly known as ‘floor-to-floor’ attenuation), and how vibration is re-radiated as ground-borne noise. Examples include (Federal Transit Administration, 2018), (Transit Cooperative Research Program, 2009) and (Railway Induced Vibration Abatement Solutions, 2012).

The aim of this paper is to examine this assumption around ground-borne noise propagation within buildings and provide some empirical data, in the form of frequency-dependent transfer functions, for a typical terrace house located in the inner suburbs of Sydney.

1.2 Policy Context

The most widely adopted policy for assessing ground-borne noise in Australia is the NSW Environment Protection Authority’s Rail Infrastructure Noise Guideline (NSW Environment Protection Authority, 2013), hereafter referred to as the “RING”. The RING is mandated on each rail project in NSW, and often voluntarily adopted in other states like Victoria and Western Australia in the absence of local or national guidance: see (AJM Joint Venture, 2016) for an example.

There are some important clauses in the RING that guide its application. One important clause is reproduced below:

“Ground-borne noise level values are relevant only where they are higher than the airborne noise from railways (such as in the case of an underground railway) and where the ground-borne noise levels are expected to be, or are, audible within habitable rooms.”

This clause is why ground-borne noise predictions are usually compared to airborne noise predictions for surface railways.

Another important clause also states:

“The noise levels represent internal noise levels and are to be assessed near to, but not at the centre of the most affected habitable room. For example, at night this may be the bedroom experiencing the highest levels of ground-borne noise, while during the day another habitable room might experience the highest levels of ground-borne noise.”

This clause should also be read in conjunction with the following:

“The ‘most-affected noise-sensitive room’ means the room where the structure-borne noise is the most significant, either in overall level, frequency spectrum or the time at which it occurs.”

The ‘most-affected noise sensitive room’ is open to interpretation to some extent. However, what these clauses regarding the ‘most-affected noise sensitive room’ mean in practice is that ground-borne noise must first be evaluated in the room(s) in which ground-borne noise is expected to be highest, at each time of the day. If it is then established that the airborne noise levels are higher than the ground-borne noise levels in this room, then other rooms, that are less exposed to airborne noise, should be considered. This can be difficult in terms of prediction if these rooms are located at a greater offset distance. It can also be difficult in terms of measurement, as those residents willing to accommodate monitoring typically expect the monitoring to be performed at the front of their houses, and are often reluctant to allow access to rooms upstairs or at the rear of their houses for privacy reasons.

Policies in other states that provide explicit guidance seem to also lean on or borrow heavily from the RING. Queensland’s Interim Guideline for Operational Railway Noise and Vibration (QLD Department of Transport and Main Roads, 2019) gives explicit instructions regarding microphone positioning within a room, but not the room in which monitoring should occur, noting other commentary about the assessment being based on a ‘worst-case’. Similarly, South Australia’s Guidelines for the assessment of noise from rail infrastructure (SA Environment Protection Authority, 2013) require that ground-borne noise is “measured and predicted near the centre of the most exposed sensitive room”.

2 MEASUREMENT SETUP

A combination of microphones and accelerometers was strategically placed around the property to monitor railway-induced ground-borne noise and vibrations. Three GRAS 146AE microphones were used to record the railway ground borne noise: two were positioned on tripods in ground-floor rooms, and one was placed in the master bedroom upstairs. For vibration measurements, three accelerometer models were used. The first, an Endevco 752A13, was wall-mounted in the master bedroom; the second, a Wilcoxon 731-207, was positioned in the rear bedroom on the first floor; and the third, PCB 393A03’s, were deployed at all other locations indicated in

Figure 2. The accelerometers were attached to the floor inside using beeswax, and magnetically mounted to a ferrous stake of 18 cm length, driven into the ground outside.



Figure 1 173 George St Redfern is a two-storey terrace house. The airport rail tunnels (dashed line on left image) run underneath George St in front of the property. (image sources: Six Maps and Google Maps)

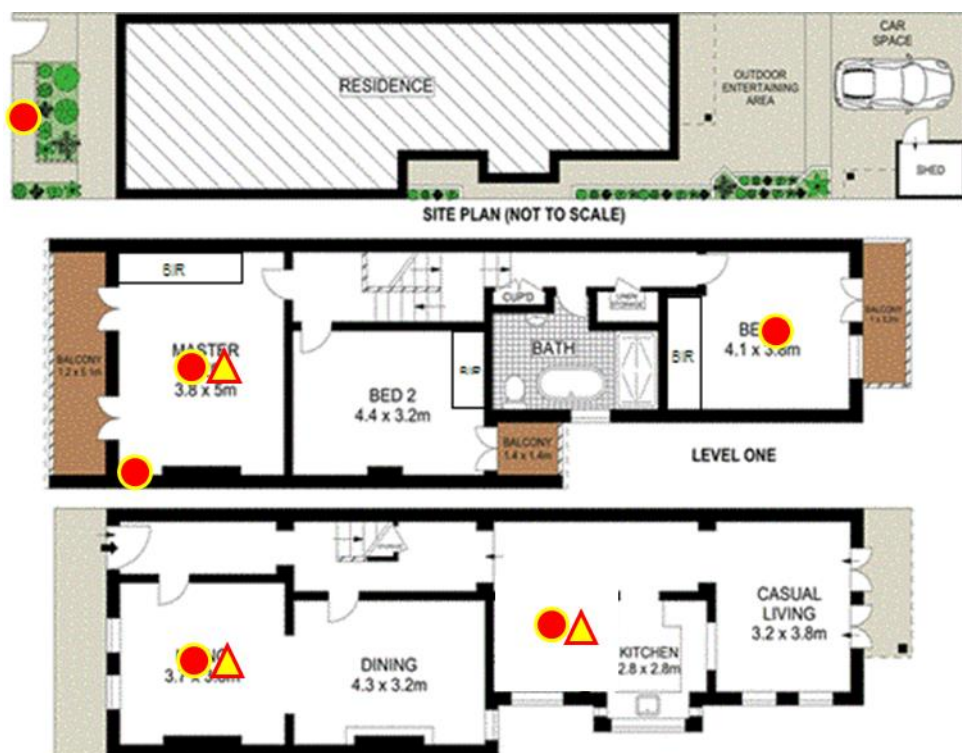


Figure 2 Sensor layout: accelerometers (red circles) and microphones (yellow triangles)¹. (image source: realestate.com.au)

¹ Note: image is from a neighbouring property. The home we measured in is the mirror-image of this figure.



Figure 3 Photos of sensors installed on the ground floor: front room (left), rear room (centre), front yard (right).

3 ANALYSIS

Individual train passes were identified by manual inspection of the overall vibration level trace from the sensor located in the front yard, cross-referenced against the Sydney Trains timetable. We calculated the LZSmax one-third octave spectrum from each train pass and excluded spectra which were affected by extraneous noise such as movements within the house or road traffic on George St. Twenty-five (25) representative train passes were extracted from the recorded data. For each of these passes, we calculated the transfer functions between the sensor locations, i.e. LZSmax one-third octave spectra at location 1 minus LZSmax one-third octave spectra at location 2, to show how vibration and noise changed throughout the residence.

4 RESULTS

At most measurement locations, ground-borne noise and vibration was clearly evident above the background over the frequency range 10Hz to 250Hz, as shown in Figure 4.

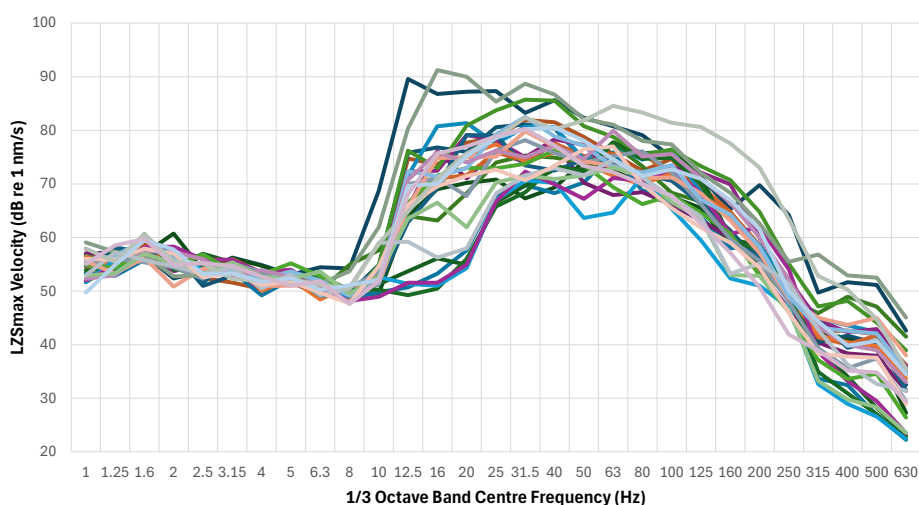


Figure 4 Train passby vibration spectra extracted from the data recorded in the front yard.

4.1 Transfer Functions

Vibration transfer functions are shown in Figure 5. Also shown are the linear averaged one-third octave spectra across all train passes, to indicate the frequency range of interest for each measurement.

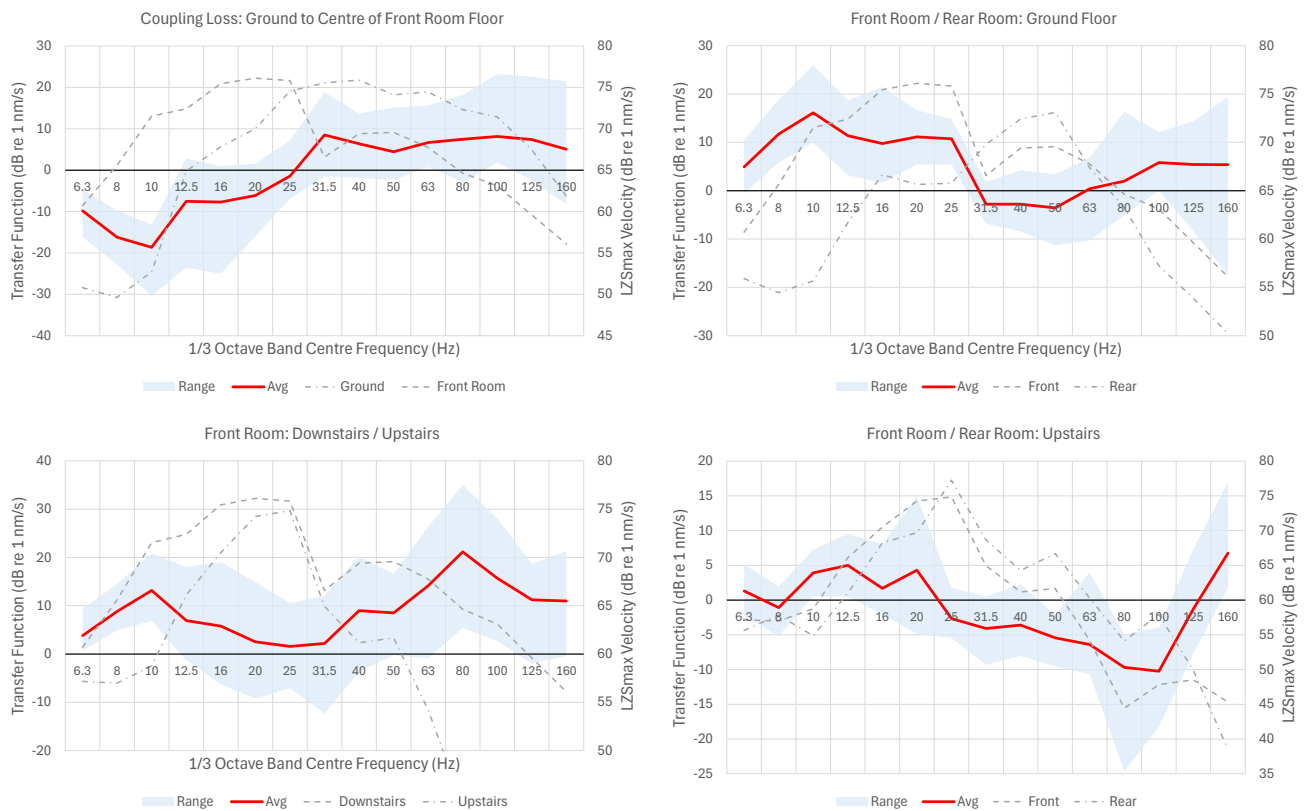


Figure 5 Vibration transfer functions (left axis): average (red line) and range (blue shaded region). The linear average spectra from all train passes (right axis) are shown as grey dashed lines.

These results show that:

- There was attenuation from the ground-floor to the first floor at the frequencies of interest for ground-borne noise.
- There wasn't attenuation from the front to the rear of the house across all these frequencies, and indeed there was amplification across this range on the first floor.

The results are based on measurements of vibration at one location, on the floor near the centre of each room, reflecting common practice in NSW for assessing ground-borne noise / vibration. It may be more appropriate and robust to measure floor vibrations at multiple locations to characterise the floor vibrations as an 'average' level, as described in (Railway Induced Vibration Abatement Solutions, 2012). It may also be appropriate to consider measuring vibrations of other radiating surfaces, such as ceilings and walls.

The results for noise were not as clear. The measured noise levels did not emerge above the ambient as much as the vibration levels, and the different room response (i.e. the transfer function between vibration and noise in each room) will be dependent on factors that were not measured, such as the contribution from other radiating surfaces, the reverberation time, and the room height (as described in (Chen et al., 2024), and was therefore difficult to account for. This aspect requires further work.

4.2 Comparison with FTA

Ground-borne noise was estimated using the FTA General Assessment method (Federal Transit Administration, 2018) based on the “Rapid Transit” source level curve and assuming propagation in rock, “1-2 storey masonry” coupling to foundation, 6dB amplification due to resonance of walls and floors, and 2dB attenuation to the second floor. The results are shown in Figure 6.

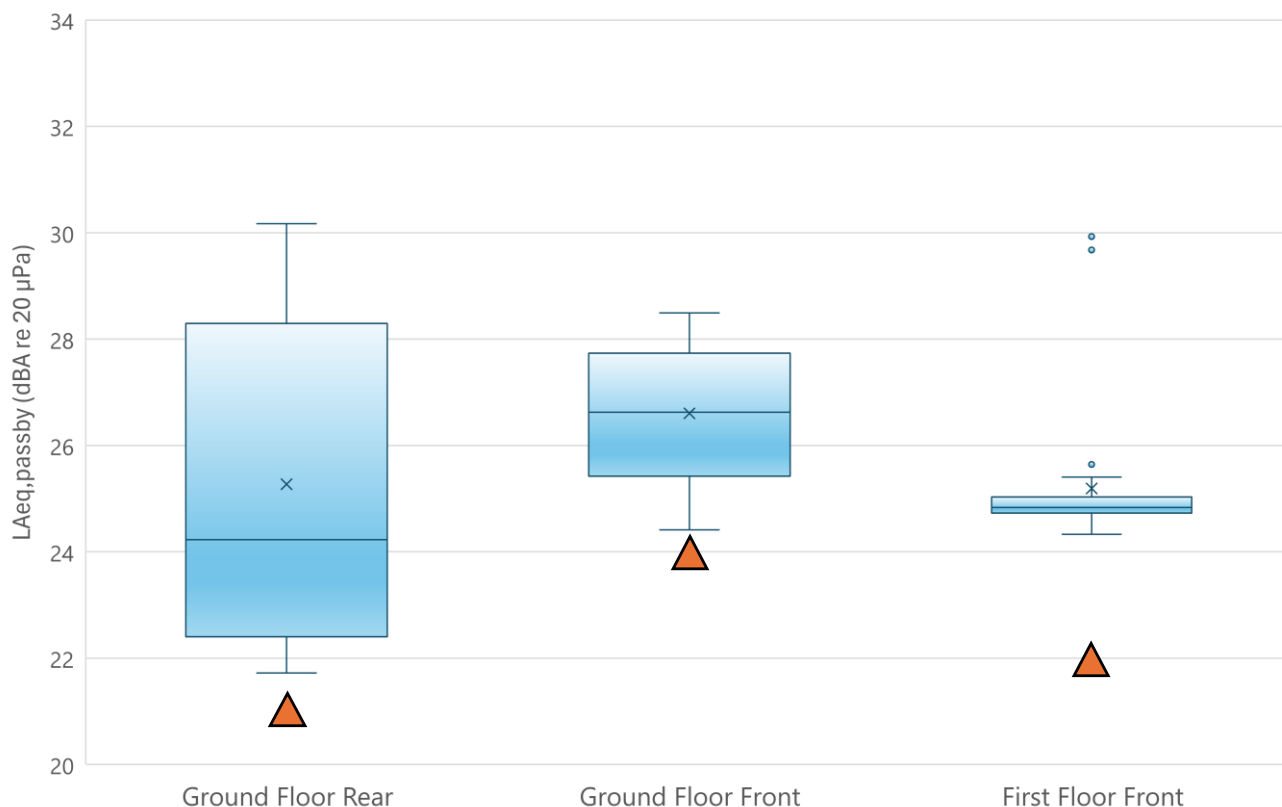


Figure 6 Comparison of the measured $L_{Aeq,passby}$ noise levels (blue) with estimates derived from the FTA General Assessment method (orange triangles)

The FTA method produced ground-borne noise estimates that were 3-4dBA lower than the mean measured level (and 16-20dBA lower than the 95th percentile $L_{ASmax,passby}$ ²). This indicates that the FTA method may be non-conservative in some cases. The underprediction was more pronounced at the rear of the property, as the vibration results in Figure 5 would suggest.

5 CONCLUSIONS

This study focused on the particular case of ground-borne vibration propagation within a terrace house in inner Sydney. The typical assumption when assessing ground-borne vibration in such dwellings is that the levels decay through the building in a similar way to their decay in the ground. The results from this case study suggest that this is not necessarily the case, and ground-borne vibration levels at the rear of the house may actually be similar to or higher than levels at the front of the house closest to the source.

² The Rail Infrastructure Noise Guideline (NSW Environment Protection Authority, 2013) assesses ground-borne noise using the 95th percentile $L_{ASmax,passby}$ noise level

This finding could have implications for ground-borne noise assessment for surface railways. Often, the assessment in these cases hinges on whether the airborne noise intrusion from the railway exceeds the ground-borne noise levels. This case study suggests, however, that ground-borne noise levels may still be significant in parts of the dwelling that are well shielded from the airborne noise. Further work is required, however, to fully explore this aspect of ground-borne noise assessment, covering a wider cross-section of building types and measurement locations.

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