A screening method to predict indicative groundborne noise and vibration from light rail and heavy passenger rail and assess impacts for human comfort

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Preliminary environmental impact assessments of rail transport projects may require prediction of indicative groundborne vibration and/or groundborne noise (GBNV) levels within nearby receiver buildings. Methods commonly used to predict GBNV generally require relatively accurate information for the vibration source(s), the intervening ground conditions and the receiver building(s). This paper provides a simple method to predict a conservative estimate of GBNV levels from light rail transit and heavy passenger rail transport vehicles in nearby receiver buildings, and provides approximate buffer zones for typical assessment thresholds.

1 INTRODUCTION

Vibration and structure-borne sound within buildings caused by ground vibration from rail infrastructure is known as groundborne vibration (GBV) and groundborne noise (GBN) (Anderson, 2004). Preliminary environmental impact assessments of proposed future road and rail projects may need to include estimates of groundborne noise and vibration (GBNV) within potentially affected receiver buildings, and to assess the severity of those impacts depending on the receiver buildings' land uses and occupancy.

Vibration of building elements and re-radiated sound is difficult to predict accurately within an individual building using first principles. Even if the ground vibration adjacent/beneath the building is known with confidence, most buildings' vibro-acoustic spectral transfer functions from the ground, through the building into any individual room cannot be accurately estimated using simple methods. In order to estimate the GBNV spectra inside a particular room within a building from an external ground-based source of vibration, it is necessary to know with confidence at least all of the following:

- the vibration source's driving force spectrum
- the vibration transmissibility of the intervening ground media
- the building's vibration coupling with the ground
- the building's vibration transfer function(s) from the foundations into the receiving space(s)' surfaces
- the receiving spaces' frequency-dependent conversion of the room's vibration into sound, which will also depend on the room's airborne sound acoustic properties.

If any of the above are not well understood for the potentially affected receivers in the vicinity of a ground-based transport corridor, then it will generally not be possible to predict accurate GBNV spectra within those potentially affected receiver buildings. However, it is possible to predict approximate, conservative estimates of overall groundborne noise and vibration levels within different types of receiver buildings.

A method is presented below with which to estimate indicative GBNV impacts, for the most common types of receivers, for the simplest configurations of rail track vibration sources and vibration propagation scenarios.

2 GBNV FROM PASSENGER RAIL TRANSPORT

A procedure to predict approximate groundborne vibration from rail transit systems is published in the U.S. Department of Transportation (Federal Transit Administration, 2018) (the FTA Manual). The FTA Manual's procedure includes algorithms and adjustments to estimate ground vibration from several types of rail vehicles, including locomotive-powered passenger or freight trains, heavy passenger rail/rapid transit (RT) or light rail transit (LRT), or rubber-tyred vehicles. The procedure provides guidance for rail track at-grade, subway, or on elevated structures, and accounts for variations in vehicle design, wheel conditions, track conditions and track vibration treatments.

The FTA Manual also provides a method to estimate the groundborne noise level within spaces inside a receiver building based on the predicted groundborne vibration of the internal surfaces of the receiving spaces' construction elements.

2.1 GBV from Light Rail and Heavy Passenger Rail, At-Grade

An indicative outdoor ground vibration level from a simple passenger rail transport system can be estimated using the FTA Manual: Equation 6-2 and Equation 6-4 (Federal Transit Administration, 2018). Considering only at-grade heavy passenger rail/rapid transit (RT) and light rail (LRT) systems, assuming typical geologic conditions, and assuming no adjustments due to irregular rollingstock, poor wheels or tracks condition, or the track support system, the estimated root-mean-square (*rms*) vibration velocity level $L_{v(outdoor)}$ for both RT and LRT is given by equation (1) (based on SI units).

$$L_{v(outdoor)} = 20 \cdot \log_{10}\left(\frac{U}{80}\right) + 112.7 - 4.15 \cdot \log_{10}(d) - 3.67 \cdot [\log_{10}(d)]^2 - 0.87 \cdot [\log_{10}(d)]^3 \qquad (1)$$

where

$L_{v(outdoor)}$ is the outdoor ground vibration level in VdB re: 1×10^{-9} metres per second

U = the rail vehicle speed (kilometres per hour)

d = distance to the centreline of track (metres)

The *rms* vibration velocity v_{rms} in metres per second is given by equation (2):

$$v_{\text{rms}} = 10^{-9} \cdot 10^{L_v/20} \quad \text{(m/s)} \qquad (2)$$

The outdoor vibration velocity level can then be used to estimate the indoor vibration velocity level within receiver buildings, taking into consideration the vibration coupling of the receiver building with the ground, attenuation of the vibration transmission floor-to-floor up through the building, and amplification due to resonances of the floors, walls and ceilings. The combination of these gains and losses is called the transfer function or Green's function.

For generic buildings, or where detailed vibration transmission information is unknown for individual buildings, a conservative estimate of the difference between the outdoor ground vibration and the indoor GBV level is:

- Small building, ground floor: +3 dB
- Small building up to 3 storeys, above ground floor: +6 dB
- Large Building: +0 dB

In the absence of information about the number of storeys of one or more small building(s), a conservative estimate of +6dB is recommended by the author and adopted herein. Therefore the following generalisation is possible to predict the approximate indoor GBV within a building, as shown in equation (3):

$$L_{v(indoor)} = L_{v(outdoor)} + K \quad \text{(VdB re: } 1\times10^{-9} \text{ m/s)} \tag{3}$$

where:

$L_{v(indoor)}$ is the indoor GBV level in VdB re: 1×10^{-9} metres per second

K = +6 (for small buildings ≤3 storeys);

K = +0 for large buildings

2.2 GBN from Light Rail and Heavy Passenger Rail, At-Grade

The FTA manual (Federal Transit Administration, 2018) provides guidance for groundborne noise (GBN) for cases where the vibration spectrum peak is near 30 Hz or near 60 Hz. Due to the large difference in A-Weighting values in the 31.5 Hz or the 63 Hz octave bands, the more conservative approach is to assume the vibration spectrum peak is ≈ 60Hz.

Conversion of some of the vibration energy in the rooms' floors, walls and ceilings into the resultant airborne sound energy density within the room depends on the radiation efficiencies of the building elements, and the acoustic properties of the room including the average sound absorption.

For at-grade track, the dominant frequency band is unlikely to be >60 Hz. If the ground's vibration transmissibility is within the typical range, and the dominant frequency is between 30 Hz to 60 Hz and is close to 60 Hz, then the A-weighted GBN level can be estimated as shown in equation (4):

$$L_{Ap,GBN} \approx L_{v(indoor)} - 63 \quad \text{(dB(A))} \tag{4}$$

where

$L_{v(indoor)}$ is the indoor GBV level in VdB re: 1×10^{-9} metres per second

$L_{Ap,GBN}$ is the indoor GBN level in dB(A)

2.3 GBNV Assessment Thresholds

For LRT and RT rail transport corridors, if the rail vehicle movements are "frequent" (≥70 per day) the assessment thresholds for human comfort recommended in the FTA Manual Table 6-3 are as shown in Table 1.

Table 1 – GBV and GBN assessment thresholds for human comfort within occupied receiver buildings

Type of receiver building	GBV Assessment Threshold	GBN Assessment Threshold
Residences and buildings where people normally sleep	100 VdB re 10^{-9} m/s	35 dB(A)
Non-residential: (Institutional land uses with primarily daytime use)	103 VdB re 10^{-9} m/s	40 dB(A)

2.4 Typical GBNV in Buildings at Distance to LRT/RT tracks vs. Assessment Thresholds

The typical GBV levels inside receiver buildings estimated by equations (1) and (3) are shown in Figure 1 and compared against the FTA Manual's recommended assessment threshold levels shown in Table 1.

The typical GBN levels inside receiver buildings estimated by equations (1), (3) and (4) are shown in Figure 2 and compared against the FTA Manual's recommended assessment threshold levels shown in Table 1.

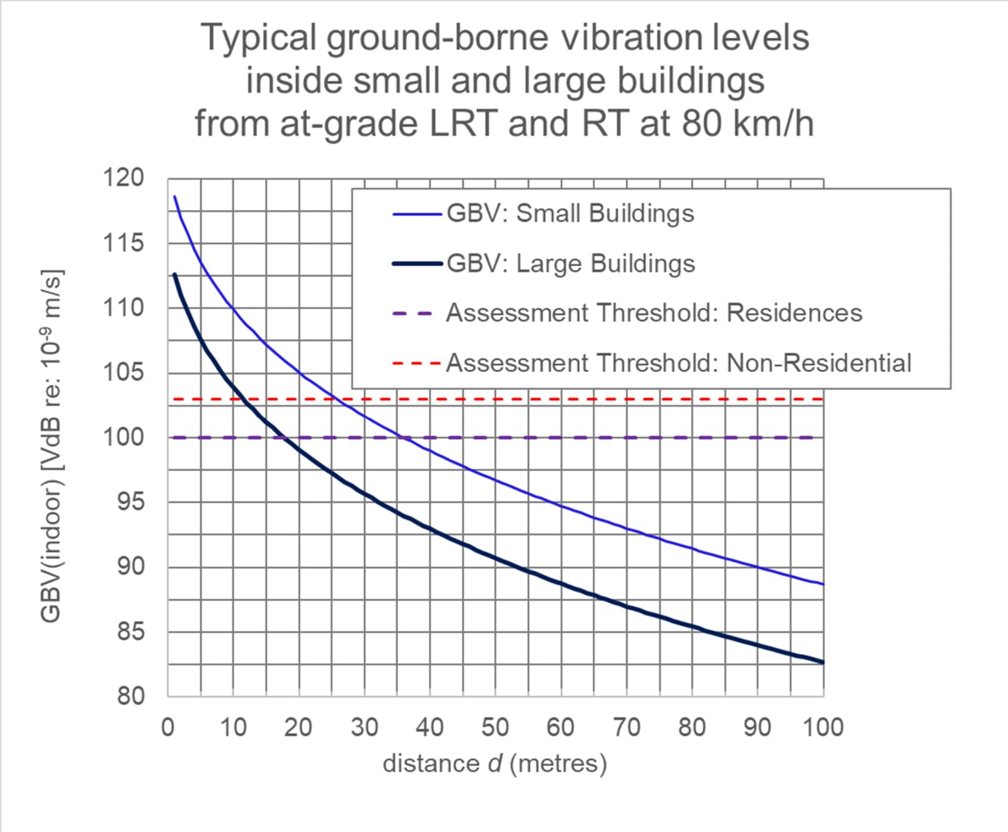

Figure 1 – Typical GBV levels inside buildings, by distance from at-grade LRT or RT tracks

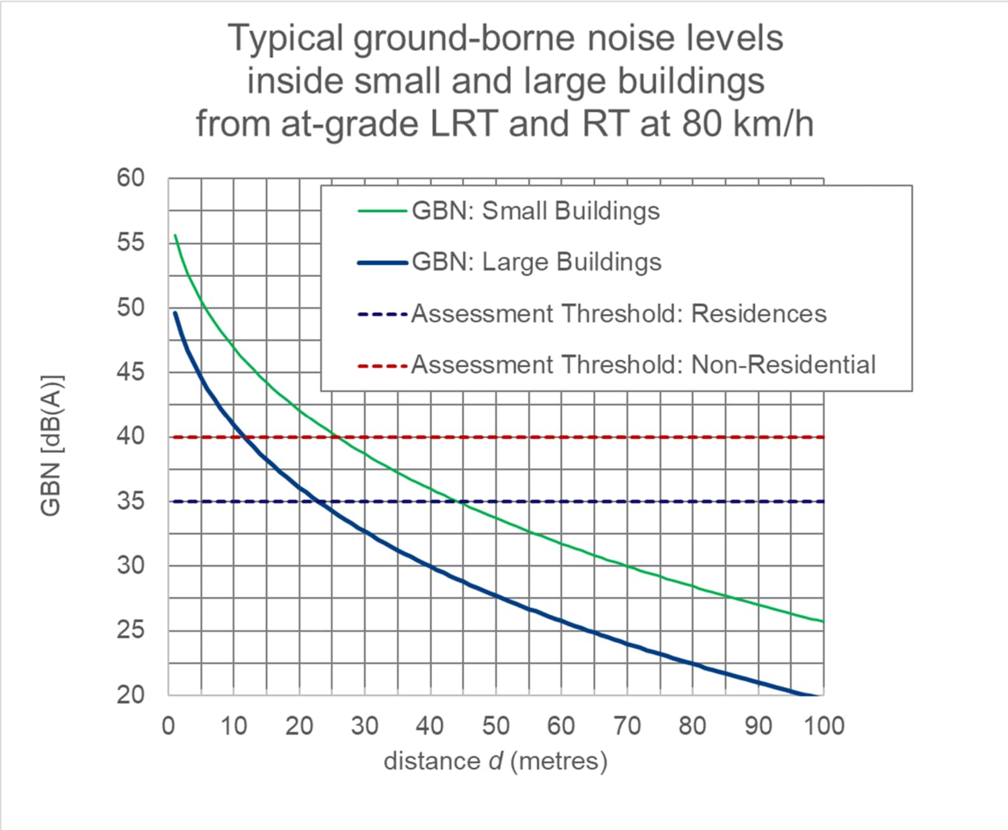

Figure 2 – Typical GBN levels inside buildings, by distance from at-grade LRT or RT tracks

The approximate distances from the tracks at which the predicted GBV levels are equivalent to the assessment thresholds, for rail vehicle speed of 80 km/h are shown in Table 2.

Table 2 – Distances from railway track where GBV level = Assessment thresholds, metres

Type of Building Occupancy	Size of Building	
	Small ≤ 3 Storeys	Large
Residences	36 m	18 m
Non-Residential	26 m	12 m

The approximate distances from the tracks at which the predicted GBN levels are equivalent to the assessment thresholds, for rail vehicle speed of 80 km/h are shown in Table 3.

Table 3 – Distances from railway track where GBN level = Assessment thresholds, metres

Type of Building Occupancy	Size of Building	
	Small ≤ 3 Storeys	Large
Residences	44 m	23 m
Non-Residential	26 m	12 m

3 SUMMARY

A simple method to undertake an indicative, preliminary assessment of groundborne noise and vibration from a light rail (LRT) or heavy passenger rail/rapid transit (RT) corridor has been derived from the US Department of Transportation's Transit Noise and Vibration Impact Assessment Manual (Federal Transit Administration, 2018).

The method is based on a number of assumptions and simplifications, and is only valid within a particular range of scenarios.

Nevertheless, in cases where indicative predictions of GBV and GBN are required for a large number of receiver buildings located in proximity to a proposed or existing at-grade rail or light rail line, the method may be able to provide useful input for a preliminary environmental noise and vibration impact assessment.

REFERENCES

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