

SUBWAY TRAIN-INDUCED NOISE AND VIBRATION IN BUILDING: PREDICTIONS AND MEASUREMENTS

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1 Introduction

Urbanization ensures that noise and vibration from rail and metro lines will continue to be an important field of research as structures coexist with nearby rail lines. The transmission of train-induced noise and vibration through building remains an active field of research. This ongoing research is largely due to the complexity of modelling the transmission of broadband vibration through the soil, into the building's foundation, and within the building itself. There are numerous approximate methods, empirically-derived models, and detailed finite and boundary element approaches available to predict train-induced vibration levels within buildings; however, the uncertainty associated with these predictions remain large, and few have been extensively evaluated with measurements.

The current study investigates the transmission of noise and vibration in a 17-storey reinforced concrete building located adjacent to the Toronto Transit Commission (TTC) Yonge-University (Line 1) and Bloor-Danforth (Line 2) lines. Vibrations are measured on the building's foundation adjacent to the metro line, and simultaneously, noise and vibration levels are measured on three elevated floors. Dozens of train passes are recorded over a measurement period of several hours, and they are observed to be the dominant source of noise and vibration within the building. In this paper, the results of the measurement program are presented, and are compared to simple rail vibration and noise prediction methodologies. These measurements add to the limited but growing body of published in-situ measurement data that is necessary to evaluate predictive models for train-induced vibrations.

2 Method

2.1 Measurements

Noise and vibration measurements are conducted on a 17-storey reinforced concrete building that is adjacent to the TTC Yonge-University (Line 1) and Bloor-Danforth (Line 2) lines. A 16-channel dynamic data acquisition system was used to record at sampling frequency of 3200 samples/second, which is sufficient to capture the typical noise and vibration frequencies produced by trains. Table 1 summarizes the locations of the accelerometers (Accel) and microphones (Mic) used in this study.

A tri-axial accelerometer was placed in the sub-

basement parking garage adjacent to the subway line, enabling the vibration levels measured at this location to be taken as the input vibrations. Vibrations are also measured on the ground floor, as well as levels 1 and 2. Microphones are also positioned near the accelerometers on all levels. Only vertical vibrations are considered in this study. Vertical vibration may propagate through the building to higher structural levels through either shear walls or concrete columns.

Table 1: Location of sensors.

Sensor Type	Level
Tri-axial Accel / Mic	P2 (sub-basement)
Tri-axial Accel / Mic	G (ground floor)
Tri-axial Accel / Mic	L1 (level 1)
Vertical Accel / Mic	L2 (level 2)

2.2 Modelling

Simplified models are employed to predict the vibration transmission within the building. The US Department of Transportation – Federal Transit Administration provides a simplified vibration assessment methodology [1]. Using qualitative descriptors of the vibration source, soil, and building, vibration attenuations and amplifications are applied to a baseline level of vibration to estimate the vibration levels that will be experienced by building occupants.

An impedance model was also employed to predict the vibration transmission through the structure [2]. The model simplified the building to be represented as an axial rod, representing a building column, with lumped masses at the locations of the floor slabs. The frequency-dependent mass and stiffness matrices are then created and used to determine the system response to a unit input at the base. Transfer functions are then generated, which can be used to predict vibration levels within the building if the base excitation is known.

3 Results

3.1 Measurement results

The measured vibrations are post-processed into 1/3-octave bands of the RMS response. Using the vibrations at level P2 as the input signal, transfer functions are created to assess how vibrations propagate to levels G, L1 and L2. Figure 1 shows the transfer functions generated from a ½-hour record during which approximately one dozen train

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passes occurred. The transfer functions generated by independent measurement records were found to be consistent with those of Fig. 1.

Fig. 1 indicates that vibrations at frequencies less than approximately 10 Hz do not attenuate at the ground floor (G) and level 1 (L1), however the vibrations at level 2 (L2) are reduced by over 50%. A resonant amplification appears to occur on floors G and L1 in a frequency range of 20-50 Hz. L2 shows a small amplification between 10-20 Hz.

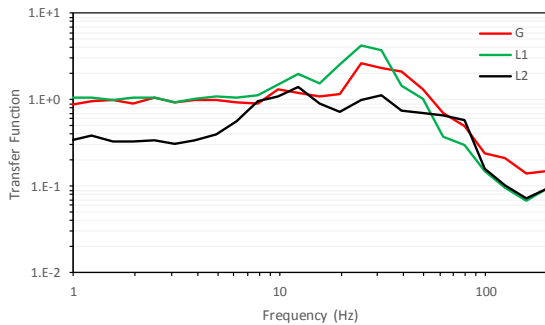


Figure 1: Measured transfer functions relating vibrations in P2 to levels G, L1, and L2.

3.2 Measurement results compared to FTA general and detailed assessment methods

A comparison of the overall vibration (“Vibn”) and sound pressure (“SPL”) levels shows good agreement with the FTA general vibration assessment results:

Table 2: FTA General Assessment Prediction Results

Location	Measured (Vibn / SPL) [VdB re $\mu\text{in/s}$ / dBA]	FTA (Vibn / SPL) [VdB re $\mu\text{in/s}$ / dBA]
P2 (sub-basement)	76 / 51	75 / 42
G (ground floor)	73 / 44	73 / 38
L1 (level 1)	72 / 34	71 / 36
L2 (level 2)	68 / 37	69 / 34

The measured sound pressure levels at P2 and G are significantly higher than the FTA general assessment results, likely due to the larger room volume and longer reverberation time in these spaces, which do not comply with the assumptions included with the FTA model.

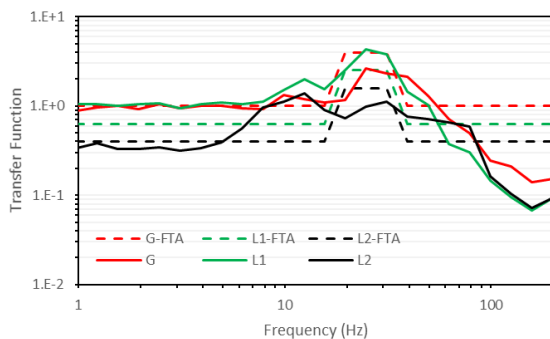


Figure 2: Predicted (FTA detailed) and measured transfer functions relating vibrations in P2 to levels G, L1, and L2

Taking the measurements at P2 as the force-density, and assuming negligible reduction in vibration due to horizontal distance from P2 to G, L1 and L2; the transfer functions from levels G, L1 and L2 were calculated based on the FTA detailed assessment methodology. As seen in Fig. 2, the modelled results are also in fairly good agreement with the measurement results.

3.3 Measurement results compared to impedance model method

Fig. 2 shows the measured results plotted alongside those predicted by the impedance model. This simplified model does not accurately predict the measured vibration amplifications on levels G and L1. Rather, the model predicts very little vibration amplification or attenuation of the floors considered over the frequency range shown.

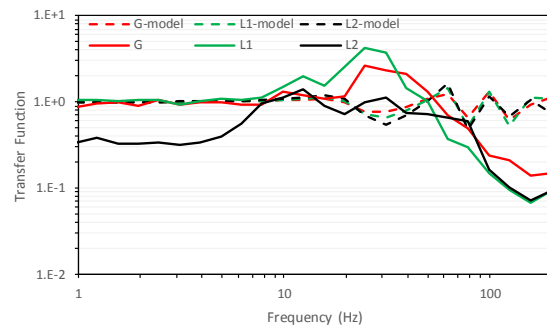


Figure 3: Predicted (impedance model) and measured transfer functions relating vibrations in P2 to levels G, L1, and L2.

4 Conclusion

Three rail vibration propagation prediction techniques are compared to measurement results in a steel and concrete structure (levels P2, G, L1 and L2). The FTA general assessment method does not require site measurements, and the results are in good agreement with the overall vibration and sound level results; however, the model lacks spectral detail. The FTA detailed assessment results include spectral predictions based on site measurements and general assumptions of the building characteristics. The results are within a reasonable agreement with the measurement result. Increased detail in the potential for floor vibration amplification would improve accuracy of the model.

The impedance model does not require measurements and yields spectral detail, however the results in this case are not in good agreement with the measurement results. Further refinement of this model should be investigated.

References

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