

# TRI-AXIAL GROUND-BORNE VIBRATION MEASUREMENTS DURING RAIL PASS-BYS

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## 1 Introduction

Ground-borne vibrations from rail pass-bys, transmitted from train wheels rolling on the rails, have the potential to cause various adverse effects, such as annoyance and re-radiated noise, at nearby receptors. To assess the vibration impact of rail pass-bys, surface-level vibration can be characterized in three components: one vertical and two horizontal directions. This paper assesses the sufficiency of characterizing the impact of ground-borne vibrations caused by rail pass-bys based on the vertical component only.

## 2 Background

### 2.1 Criteria and Guidelines

Ground-borne vibration measurements are often conducted to assess the impact of rail-induced vibration on new developments that are in proximity of railway operations. In Canada, the Railway Association of Canada/Federation of Canadian Municipalities' (RAC/FCM) New Development in Proximity to Railway Operations document [1] establishes requirements for conducting such vibration measurements and provides an RMS vibratory velocity criteria at 0.14 mm/s, over which vibration mitigation is required on and above the first floor of the dwelling. In the more technically rigorous guideline from the Federal Transit Administration (FTA) on rail vibration [2], which is also referenced in the Canadian RAC/FCM guideline, it is described that the measurement in only the vertical component is sufficient, as the vertical component typically dominates.

### 2.2 Theory

In Woods et al [3], ground-borne vibration in an elastic half-space medium, which can represent an ideal soil medium, propagates with P-waves, S-waves, and Rayleigh waves that each have different characteristics. P-waves (compression) and S-waves (shear) are body waves that propagate hemispherically down from the source and exhibit push pull and transverse/perpendicular motion with respect to the direction of the wavefront, respectively. Rayleigh waves are surface waves that exhibit horizontal and vertical motion in an elliptical pattern at the surface with a larger vertical component.

In cases involving vertical loads on a circular footing with homogenous and isotropic soil, P and S-waves contribute to 7% and 26% of the total energy, respectively, and dampen at a rate of  $1/r^2$  along the surface. Comparatively, Rayleigh waves accounts for 67% of the total energy, and dampen at a rate of  $1/r^{0.5}$  along the surface. As such, it is

expected that the vertical component will become more dominant as distance from the vibration source increases due to Rayleigh wave propagation.

## 3 Measurement Methodology

Surface trains (Metrolinx commuter GO-trains on the Milton line) were measured in Mississauga, Ontario, in a flat, landscape parking lot situated in a low-rise residential and commercial area. The tracks are at-grade with the parking lot and is slightly curved with no nearby at-grade intersections. The trains were travelling at approximately 75 km/h.

Since it is not always possible to fix transducers directly onto existing foundation elements, as is the case with new developments, an alternative method of fixing the transducer is needed to ensure good coupling with the soil. To evaluate coupling methods, preliminary trial measurements were conducted using round ground stakes, magnetic coupling to existing concrete bollards, ground stakes with X-shaped cross sections, and unburied concrete blocks. The results of these preliminary measurements are summarized in Table 1 and show that different coupling methods can significantly impact the measurement results.

In this paper, the X-axis is defined as perpendicular to the rail tracks on the horizontal plane, the Y-axis as parallel to the rail tracks on the horizontal plane, and Z-axis to be the vertical plane.

**Table 1:** Maximum RMS Acceleration [dBg] at 30 m from Tracks for Varying Transducer Coupling Methods

Coupling Method	X	Y	Z	Notes
Round Stake	-62.0	-61.1	-64.1	Can have poor X & Y coupling due to soil conditions
X-Shaped Stake	-64.1	-65.7	-65.9	Better coupling than round stakes.
Concrete Block on Grass	-50.3	-57.4	-58.0	Bad coupling overall. Axis-dependent response: 40 Hz, 20 Hz, and 12.5 Hz dominant in Z, X, and Y-axis, respectively.
Concrete Block on Pavement	-63.4	-60.1	-64.2	Low levels except for abnormally high levels at 125 Hz in all directions.
Existing Concrete Bollard with Metal Sleeve	-58.7	-59.8	-61.3	Z & Y dominated by abnormally high levels in 250 Hz. Possible excitation of bollard vibration modes.

The ISO standard 14837-31 [4] provides guidance on methods of fixing vibration transducers to measure ground-borne vibration and noise from rail systems, including the

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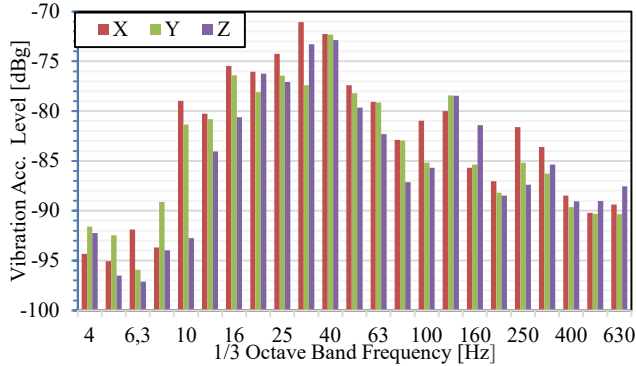
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usage of cross-shaped stakes to ensure good coupling with the soil. While a detailed investigation of the adequacy of coupling methods is beyond the scope of this investigation, the results and literature support the used of X-shaped ground stakes. Thus, the transducers were coupled to the ground using X-shaped ground stakes in this study.

## 4 Results

Two triaxial accelerometers (PCB 365A16) were placed at approximately 15 m and at 30 m from the railway tracks, recording RMS levels averaging to 1 second.



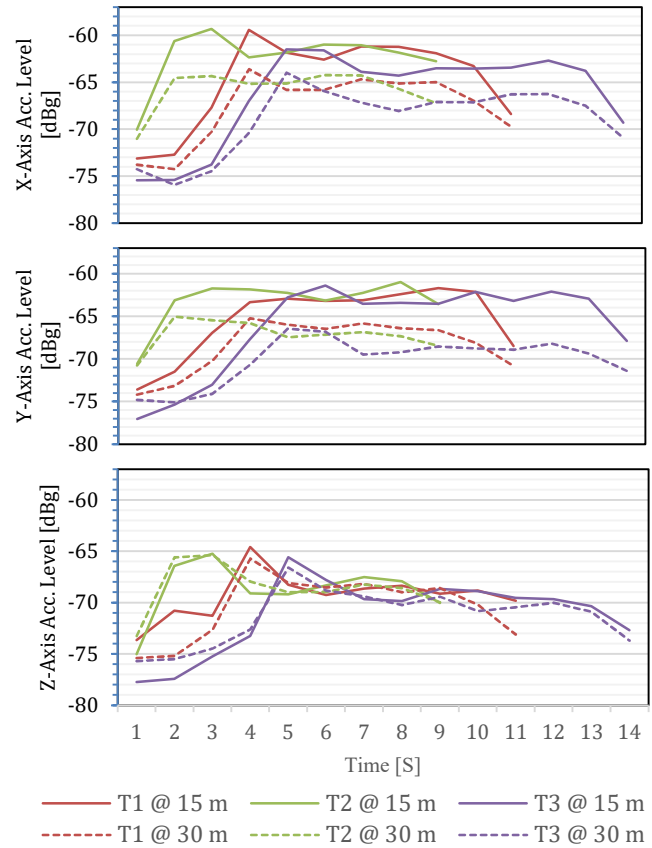
**Figure 1:** Typical Maximum RMS Acceleration [dBg] of Pass-By at 30 m from Tracks, Using Cross-Shaped Stakes

Figure 1 above shows the typical vibration spectrum measured of a train pass-by, and Figure 2 below shows the vibration levels for three trains, with both figures showing RMS levels.

## 5 Discussion

At a closer distance to the tracks, the results show that horizontal components can be greater than the vertical component, potentially due to higher energies from compression and shear waves. Based on wave propagation theory, the body waves at the surface attenuate at a higher rate than Rayleigh waves, which contributes to a higher vertical component relative to horizontal components at greater distances from the vibration source. This is supported by the measured data, since the peak vibration levels at 15 m and 30 m from the railway tracks were attenuated in the X and Y-axis by up to 4 dB and 6 dB, respectively, whereas levels in the Z-axis remained more constant, attenuated by up to 1 dB.

As expected, the horizontal components attenuate at a higher rate than the vertical component as distance from rail tracks increases. However, despite expectations, the vertical component does not dominate over the horizontal components when measured at a distance of 30 m, which is typically the minimum setback distance for new residential developments adjacent to mainline rail tracks under RAC/FCM guidelines. Nevertheless, the measured vertical component is similar to those in the horizontal components to within 2 dB of the horizontal components, which is noted to be within the error range of  $\pm 3$  dB of the RAC/FCM guideline for vibration measurement requirements.



**Figure 2:** Measured Vibration Levels in X, Y, and Z-axis at 15 m (solid lines) and 30 m (dotted lines) for three pass-bys.

## 6 Conclusions

Based on these findings, measurement of rail-induced ground-borne vibration can be sufficiently characterized by measuring the vertical component, provided that there is sufficient distance separating the measurement location for compression and shear waves to attenuate. For the measured passenger trains at this specific location, the results suggest that a distance of 30 m is sufficient.

Future work is encouraged on two fronts: 1) to further refine transducer coupling method, since it is evident that a comparison of axis-specific vibration levels cannot be conducted without adequate coupling, and 2) to verify the results with other source parameters, such as train type, speed, and geometry.

## References

- [1] The Railway Association of Canada and the Federation of Canadian Municipalities, *Guidelines for New Development in Proximity to Railway Operations*, Ottawa, ON, May 2013.
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- [4] International Organization for Standardization, *Mechanical Vibration – Ground-borne Noise and Vibration Arising from Rail Systems – Part 31: Guideline on Field Measurements for the Evaluation of Human Exposure in Buildings*, ISO-14837-31, Switzerland, 2017.