ASSESSMENT AND PREDICTION OF STRUCTURE-BORNE RAIL NOISE IN DOMESTIC DWELLINGS

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Abstract

The aim of this paper is to provide findings based on a study on the existing structure-borne rail noise levels in order to facilitate the decision making on any future expansions in Sydney. The study focuses on prediction of structure-borne noise levels using an algorithm which takes into account the geology, the vibration transfer coupling between the ground and a typical dwelling, the efficiency of the floor to re-radiate the vibration and typical acoustic properties of a dwelling. With the experimentation conducted in various locations around Sydney, a consensus was drawn on the noise and vibration assessment according to the geology of the region. The predicted structure-borne rail noise is to be juxtaposed with the measured data to suit the conditions in the areas concerned.

1. Introduction

With the increasing urbanization trend, excessive transport is a necessity and with this the issues related to it appear predominantly. The structure-borne rail noise is of major concern in terms of its effects on the community [1]. This requires acoustic engineers to plan and contribute for future rail way developments in densely populated areas to provide acceptable level of noise to the community of interest. Hence the task involves development of prediction methods of the structure-borne rail noise in domestic dwellings. This study focuses on prediction of structure-borne noise levels using an algorithm which takes into account the geology, the vibration transfer coupling between the ground and a typical dwelling, the efficiency of the floor to re-radiate the vibration and typical acoustic properties of a dwelling.

Locations were meticulously scrutinized in context to the intensive network of rail lines in Sydney metropolitan area. Based on locations around each rail line, a specific location was to be identified having a rail track adjacent to the road for the purpose of measurements. Deliberately, a location with no bridges, no under-pass and no inclination on tracks or roads was chosen for appropriate analysis of the data collected.

The analysis of the measurements and the development of an algorithm were done using interactive software, Samurai Version 2.4.1@ 2009-2013 SINUS Messtechnik GmbH, which is used for presentation, calculation, assessment and prediction of noise mostly environmental. The selection of this particular software for the purpose of measurements was chosen due some of its unique features in noise prediction that includes being the fastest noise prediction software in the market. The main approach behind this is to identify the noise and vibration levels at a specific location and the possible effects on the community around. Having the algorithm in hand, possible suggestions or recommendations can be made in terms of expansions or reductions in the existing rail project.

Dawn et al. [2] in their experimentation measured both horizontal and vertical acceleration on a wall parallel to the railway track in order to obtain the vibration velocity. On analysis, the authors recorded increased levels with increasing speed and a stronger effect over the range of 1/3 octave bands for the bulk carrier wagons by 20Hz when compared to a normal passenger train. As discussed in the paper, the total vehicle mass is considered an important factor than the associated unsprung mass which is not adequately explained in relation to the velocity propagation of the ground disturbances. Furthermore, the experimentation technique is in conjunction to the approach used for the vibration analysis of this topic if considered at a single distance for all the three components of the vibrations.

These measurements were then to be compared to the open field measurements in order to identify the variations in the recordings. Figure 1 displays the experimental setup with a tri-axial accelerometer on asphalt, which is equivalent to the setup being used in our study if done at a single distance for every location. The direction parallel to the track was labelled as longitudinal and the direction perpendicular to the track was named as transverse.

Figure1. Tri-axial accelerometer setup [2]

2. Experimental Methodology

Computational analysis of this particular study has been facilitated by the use of a software package for noise and vibration measurements i.e. Samurai Version 2.4.1@ 2009-2013 SINUS Messtechnik GmbH. As a setup, “SPS-18 Train Pass-by” has been used which has the predefined settings for this particular experimentation. Soundbook_MK2 is a portable measuring device for vibration and is used for acoustic and other engineering measurements. This device has exceptionally reputed records for its measurements in sound level measurement, frequency analysis, pass-by noise measurement, building acoustics and even human vibration measurement. The Samurai interface is shown in Figure 2. This soundbook equipped with Samurai Version 2.4.1@ 2009-2013 SINUS Messtechnik GmbH is used for the experimentation. This device includes an Apollo box having 4 channels for operation with a USB 2.0 interface. As an alternative for the measurement of the noise levels, NTi manufactured XL2 is used as shown in Figure 3. It is a unique combination of a Sound level meter, powerful Audio analyzer as well as a comprehensive Acoustic analyzer. The XL2 is a complex engineered device which is capable of not only measuring the noise levels but also the FFT high resolution spectra, RTA, RT60 reverberation time, delay and has many more applications. The data and audio can be transferred to a computer using the XL2’s SD card. For the analysis, XL2 Data Explorer software is utilized to view the logged noise monitoring data.

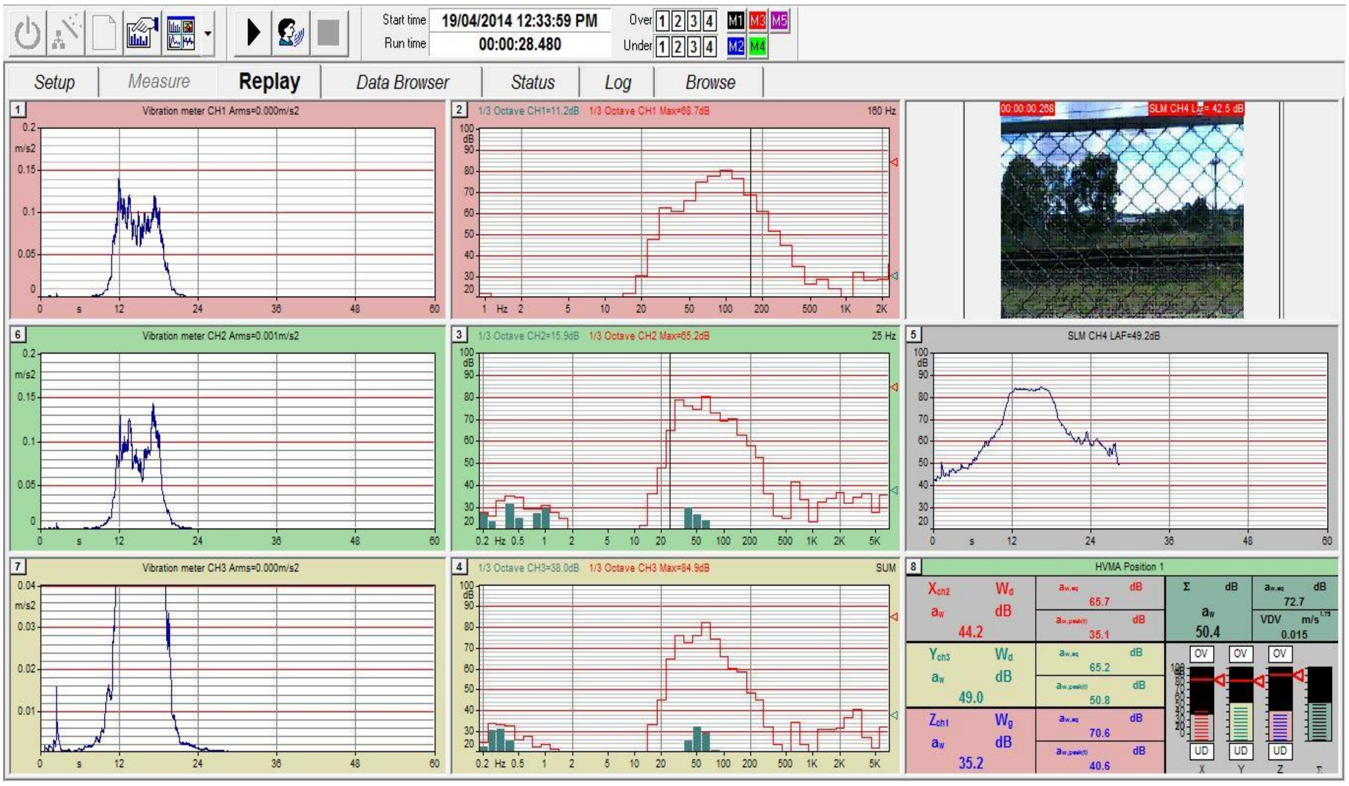

Figure 2. Samurai Version 2.4.1 Interface

Figure 3. NTi XL2

For this specific study, meticulous selection for test sites was conducted in order to locate a perfect location conforming to the test requirements. Each test site was supposed to be analyzed at four different distances in an arithmetic progression of 8m from the nearest accessible point to the railway track i.e. 8 m from the center of the track. At each particular distance, approximately 20 - 25 recordings were conducted in order to get a mean for better analysis of the situation.

For the experimentation to be conducted, initially a decent location was selected which was in the vicinity of a train station but still at a reasonable distance so as to get the recordings for the trains passing by at desirable speed. For instance, the first site, which was selected, is approximately 1.5km from the nearest railway station for a legitimate analysis regarding the speed of the train. Initially, the railway track was analyzed for any discontinuities or any attachments so as to make sure that the vibration propagation is not amplified by any external element. Equipment included was a soundbook installed with the Samurai application and the accelerometers (for each direction i.e. x, y, z), sound level meter, microphone, calibrator, usb-camera, tripod stand, hammer, super-glue, double-sided tape and a digital single-lens reflex camera are attached to it. Figure 4 shows the arrangement. This was the initial setup during the testing phase of the efficacy of the measurements.

Figure 4. Experimental set up

A normal train pass-by being analysed lasted for around 20-25 seconds depending on the speed of the train. For each site, 25-26 train pass-by's were recorded and averaged for an efficient analysis for that particular site. Mean averaging of the r.m.s. acceleration values and the sound exposure values provided a single set of values for each distance, out of which line graphs were plotted to provide a better understanding of the actuality. For each particular site, two different sets of analysis were conducted in which trial measurements were recorded for the closest distance to the railway track and for the other one all four distance including the wall were assessed. Critical frequency range was the next task to be figured out as it helps to disclose the frequencies that are important while giving any recommendations.

After picking out the crucial 1/3 octave band frequencies, plots were created for the r.m.s. acceleration values vs. 1/3 octave band frequencies. For each particular crucial frequency, plot for the r.m.s. acceleration vs. logarithmic distance was created in order to analyse the decay rate for each frequency including three points representing the different distances being analysed excluding the wall condition. Even individual decay rates were plotted with respect to each measurement in the form of a histogram. After getting the line equation from each of the measurements, an average decay rate was calculated using the slope of the lines to form an algorithm for the particular frequency as given below:

$$a_1 = a_0 - Average\ Decay\ Rate\left(\frac{D_1}{D_0}\right) \quad (1)$$

where a_0 is the r.m.s. acceleration value for distance 1 (D_0) and a_1 is the r.m.s. acceleration value for distance 2 (D_1).

3. Results and Discussion

For the first site i.e. Phoenix Avenue near Ingleburn Rd, Ingleburn the test area is shown in Figure 5. Measurements were done and the Excel files were imported from Samurai interface for all the recordings. In this particular experimentation, all the distances (i.e. 13 m, 21m and 29 m from the track and approximately 35 m from the track for the wall) were measured at the same instance different to what was done in the previous experimentation.

Figure 5. Test Site – Phoenix Avenue near Ingleburn Road

For Site 1, Figure 6 displays the average of the r.m.s. acceleration vs. 1/3 octave band frequency in the form of a line graph. As expected prior to the experimentation, the r.m.s. acceleration values for distances closer to the track were reported to be higher than the others. Similar results were achieved when juxtaposed with the experimental results. In reference to the figure, the maximum average r.m.s. acceleration value appeared for the location 13m away from the track to be 70.66 dB re 10^{-5} m/sec^2 at 80Hz. The blue line depicts the distance i.e. 13 meters from the railway track. The red, grey and yellow lines depict the distances i.e. 21 meters, 29 meters and the wall respectively from the railway track. Floor noise represent similar distances as done for the r.m.s. acceleration values. These lines represent the noise of the instrument by carefully analyzing the r.m.s. acceleration values from the time history relating to 1 second time before the train actually passed by. The peaks for the r.m.s. acceleration values for the various distances conform to the theoretical observation. Another observation analyzing the frequency displayed a certain frequency range from 10Hz - 80Hz at which an inclination pattern was witnessed. Due to huge variations in the r.m.s. acceleration values, the crucial frequency range appears to be from 10Hz - 400Hz. Figure 7 represents the same r.m.s. acceleration vs. 1/3 octave band line graph for the most crucial 1/3 octave band frequencies.

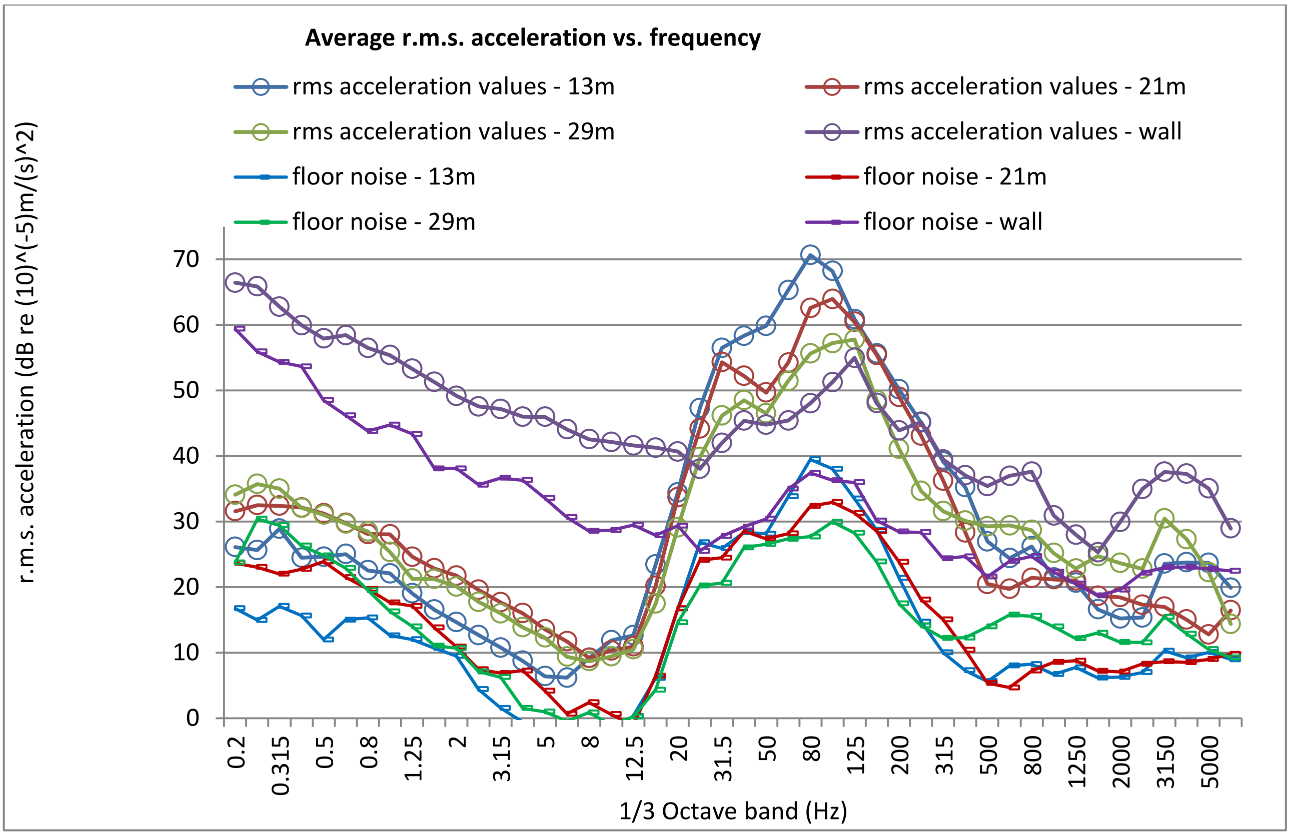

Figure 6. Average r.m.s. acceleration vs 1/3 octave band

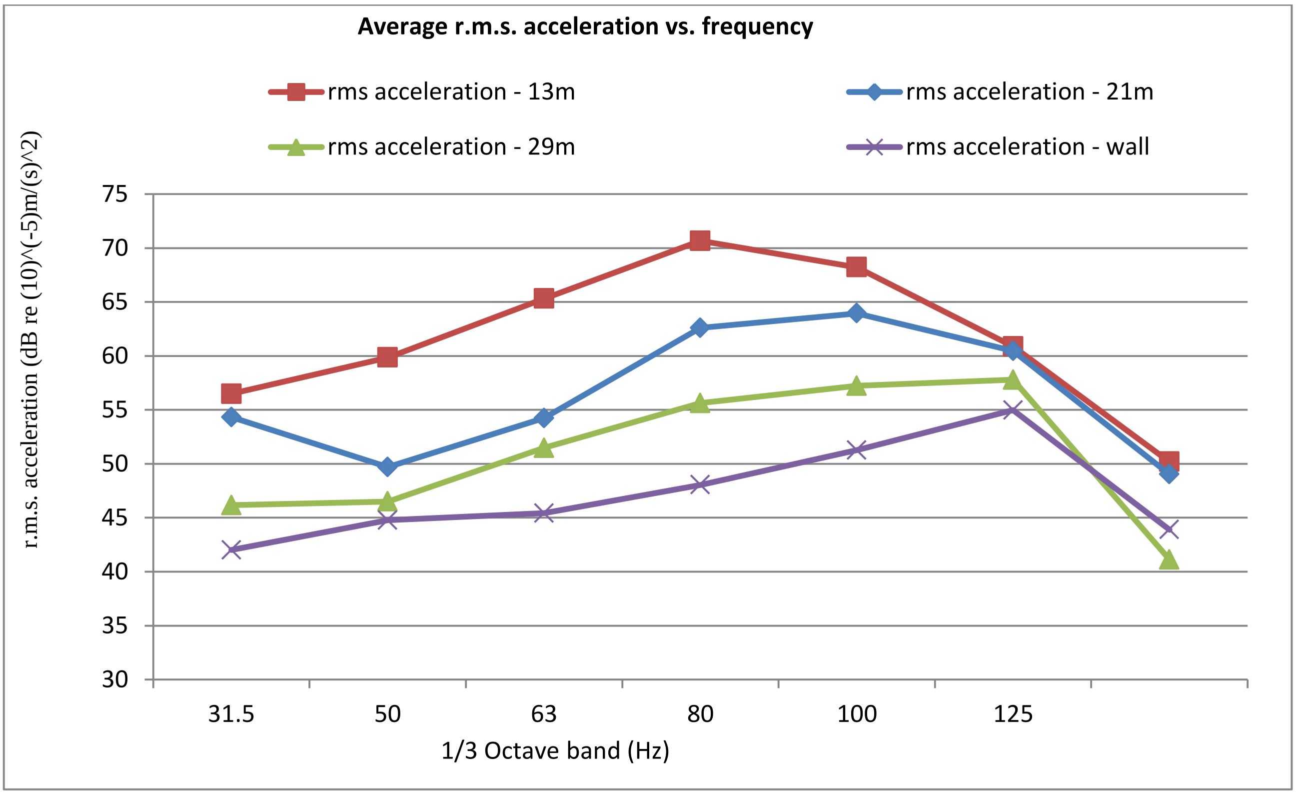

Figure 7. Average r.m.s. acceleration vs 1/3 octave band

For each particular crucial frequency, plot for the r.m.s. acceleration vs. logarithmic distance was created in order to analyse the decay rate for each frequency as shown in Figure 8. After getting the line equation from each of the measurements, an average decay rate was calculated using the slope of the lines to form an algorithm for the particular frequency including three points representing the different distances being analysed excluding the wall condition. For frequency level at 31.5 Hz, an average decay rate of -21.06 was calculated and a general equation for any distance is given by:

$$a_1 = a_0 - 21.06(\frac{D_1}{D_0}) \quad (2)$$

A histogram chart type was used to represent the individual decay rates with respect to each measurement conducted. Figure 9 shows the Decay rate vs. measurements graph indicating the individual decay rates obtained from the slope of the lines as shown in Figure 6 in the form of a histogram with its corresponding measurement.

A similar procedure was followed to obtain a r.m.s. acceleration vs. logarithmic distance graph for 50 Hz and average decay rate of -29.19 was calculated. Based on this, an equation for any distance at that frequency is given by:

$$a_1 = a_0 - 29.19(\frac{D_1}{D_0}) \quad (3)$$

For all the important frequencies, similar expression was utilised to measure the r.m.s. acceleration values for distance corresponding to the decay rate calculated using the slopes obtained from the logarithmic distance slopes. The excel sheet showing the decay rate calculation for 31.5 Hz is depicted in Figure 10. The average decay rates for all the different frequencies are shown in Figure 11.

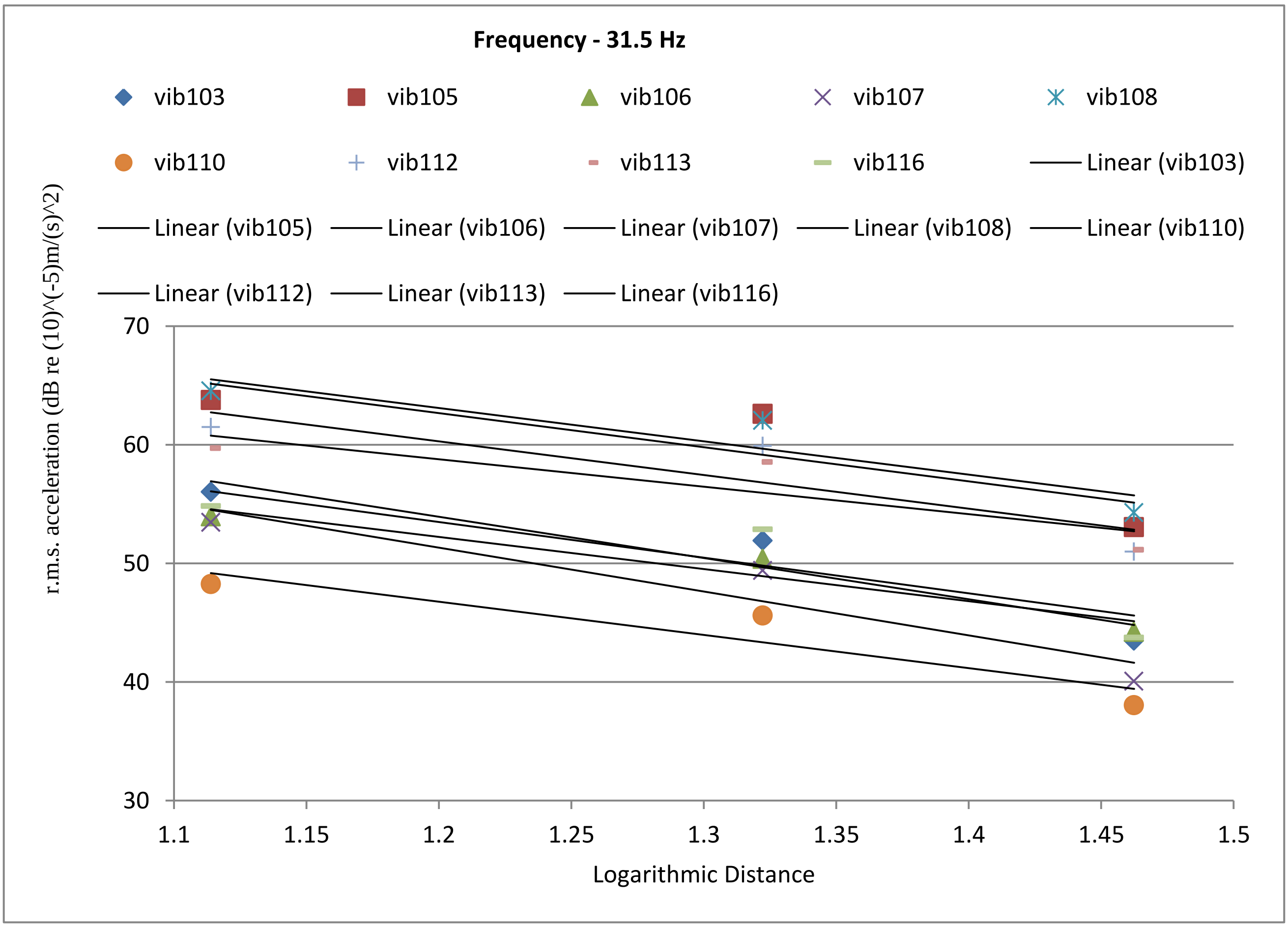

Figure 8. Average r.m.s. acceleration vs logarithmic distance (31.5Hz)

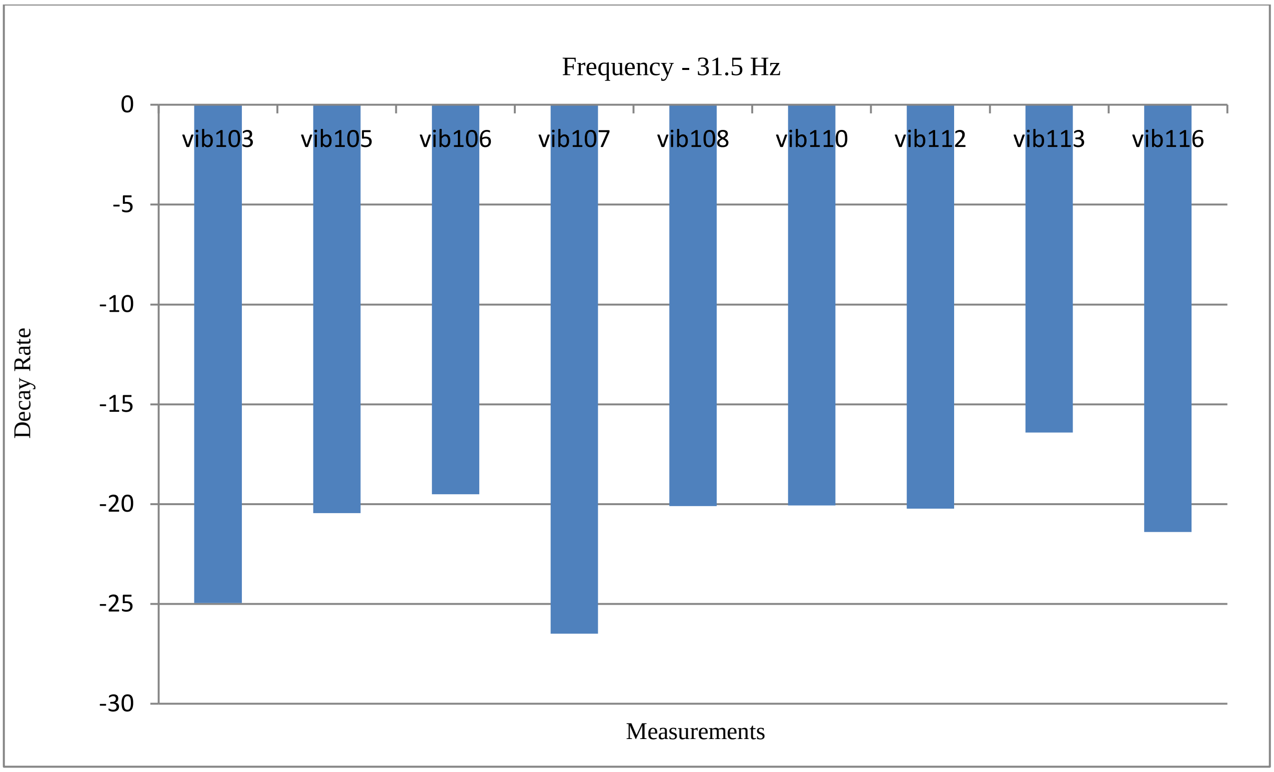

Figure 9. Decay rate vs measurements (31.5Hz)

	A	B	C	D	E	F	G	H	I
1	Measurements	Distance 1	Frequency	Distance 2	Frequency	Distance 3	Frequency	TRENDLINE	r square values
2		13	31.5	21	31.5	29	31.5		
3	vib103		56.0		51.9		43.5	-24.953	0.8854
4	vib105		63.8		62.6		53.1	-20.452	0.7038
5	vib106		54.0		50.4		44.2	-19.508	0.9125
6	vib107		53.5		49.4		40.1	-26.494	0.8673
7	vib108		64.6		62.0		54.3	-20.097	0.8215
8	vib110		48.3		45.6		38.0	-20.059	0.833
9	vib112		61.5		59.9		51.0	-20.233	0.7433
10	vib113		59.7		58.6		51.1	-16.418	0.7263
11	vib116		54.8		52.9		43.8	-21.389	0.764
12	Log Distance	1.113943		1.322219		1.462398			
13	AVERAGE							-21.067	0.806344

Figure 10. Decay rate with respect to measurements (31.5Hz)

1	Frequency	Average Decay Rate
2	31.5	-21.067
3	50	-29.192
4	63	-30.121
5	80	-41.062
6	100	-30.924
7	125	-8.765
8	200	-29.37

Figure 11. Average decay rates with respect to frequencies

The noise measurements for the first distance (D_1) i.e. 13 m was recorded to be 75.2 dB(A) as an average over the 15 minutes using the NTI XL2 after logging the data into the computer. The sound pressure level (L_{P2}) at the second distance (D_2) i.e. 21 m was recorded to be 71 dB(A) using the basic formula for the noise measurement calculation, that is

$$L_{P2} - L_{P1} = 20 \log_{10}(\frac{D_1}{D_2}) \quad (4)$$

The estimated sound pressure level at the second distance is 71.4 dB(A) which is very close to the recorded ones. The sound pressure level at the third distance i.e. 29 m was recorded to be 68 dB(A) which is also very close to the calculated value using the same formula as mentioned above. All these sound pressure level values are the averages of the maximum sound pressure levels of the train pass-by's recorded for the period of 15 minutes Slight variations in the measurements are understandable due to the continuous incoming traffic and its related effects.

As done for 31.5 Hz, similar procedure was followed to obtain a r.m.s. acceleration vs. logarithmic distance graph for the rest of the frequencies i.e. 50 Hz, 63 Hz, 80 Hz, 100 Hz, 125 Hz and 200 Hz. Using similar technique, results were found for the remaining three locations, which complied with the pattern of the first location. The results obtained in this study along with numerical modelling [3,4] along with control mechanisms suggested by Wilson et al. [5] could lead to development of appropriate algorithm for structure-borne noise prediction in domestic dwellings.

4. Conclusions

The experimentation validates the results as each channel conforms to the theoretical aspect of the concept of noise and vibration. As the distance increases from the railway track, the line plot keeps on decreasing and presents a pattern with higher altitudes for distances closer to the track. Juxtaposing all the average maximum r.m.s. acceleration and sound exposure values, the frequency range from 10 Hz – 400 Hz appears to be of utmost concern as all the maximum average values have been recorded under this frequency range. Particularly, frequency around 80Hz plays a pivotal role, considering the maximum average values have been generated around this frequency. This study has involved different train types running in Sydney (i.e. M Set (Millennium), A Set (Waratah) and T Set (Tangara) running in a speed range of 70 km/hr to 90 km/hr. These findings are effective when measured along flat ground conditions free from under-pass and bridges. The distances at which the measurements are to be made must be an arithmetic progression of 8m starting from the closest accessible proximity of the train track. Each frequency band has its unique decay rate, which depends upon many related factors like the area's topography, weather conditions, soil properties, moisture content and many others. With the decay factors for each particular crucial frequency, a consensus can be achieved for the assumption of the vibrational effects on the domestic dwellings in the vicinity of a railway track.

Having completed this study authors strongly believe future work is to be done more comprehensively to develop an algorithm which accounts for the relationship between the vibration transfer coupling and the re-radiation of the domestic dwellings can be the continuation for this study. With the proper algorithm based on how much vibration levels can be felt inside a domestic dwelling, prediction on the implications of the transit projects would be possible.

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