What annoyed me – vibration or low-frequency noise?

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ABSTRACT

It has been identified by the Western Australian Department of Environment and Conservation (DEC) that many complaints regarding vibration problems are actually noise problems. The DEC recently received a complaint about railway operations from a resident in the Perth suburb of Canning Vale. The complainant targeted vibration as the problem, indicating that the whole house was vibrating when the freight train passed by. Investigations conducted by the DEC indicated that while the vibration level inside the house was significantly elevated when there was a train passing-by, the levels were not high enough to cause a problem, as they were all far below Curve 1 specified by AS2670.2-1990. The A-weighted noise level inside the house, though also elevated during the train operation, was also below a level that normally attracts complaint. Further analysis of the measured data indicated that low-frequency noise might be the major issue. Very strong low frequency noise energy in the range from 12-32 Hz was recorded inside and outside the house. However, because the building structure is more efficient in attenuating the high-frequency noise, the low-frequency energy becomes more obvious inside the house. The difference between C and A-weighted noise levels increased from 20 dB outside the house to more than 30 dB inside the house. The analysis identified that the size and shape of a room might also contribute to the higher level of low-frequency noise inside that room. This study also indicated that there is the possibility that the low frequency noise may be due to regenerated noise from ground vibration.

INTRODUCTION

The Environmental Noise Regulation Branch of the Department of Environment and Conservation (DEC Noise Branch) from time to time receives complaints from the community about vibration problems, such as the vibration from pool pumps, from railway operations and from commercial laundries. Quite often, the subsequent investigations indicate that it is not the vibration, but the low-frequency noise that is to blame in these complaints. A quite recent complaint made by a resident about vibration from trains is a good example demonstrating this problem.

A resident living in Perth's southern suburb of Canning Vale contacted the DEC Noise Branch in February 2009 complaining about vibration generated by freight trains. The resident lives a row of house that back onto the railway, at a distance of about 50 metres from the railway track. According to the complainant, the vibration level generated by the freight trains is more annoying in the early morning, due to the increased train speed in the early morning and increased frequency of train movements. The local Member of Parliament had also contacted the Minister for the Environment on behalf of a group of residents with similar complaints. In response to the residents' complaints, the DEC Noise Branch conducted a noise and vibration monitoring programme at the original complainant's residence.

The purpose of this investigation was to collect data on noise and vibration generated by trains, at locations both inside and outside the residential building, and to assess the ground-borne vibration and air-borne noise against relevant criteria.

METHODOLOGY

The rail noise and vibration investigation was conducted by using a Rion DA-20 4-channel Data Recorder and a Sony PC 204 Digital Tape Recorder. Both were installed at the complainant's residence in Canning Vale over the period 27 March to 17 April 2009.

The Rion DA-20 recorder was installed inside the house to measure both the vibration and noise inside the house. The vibration transducer was a three channel Rion PV-83 accelerometer mounted on a single block to obtain X-Y-Z direction vibration levels, and a Rion VP-80 three-channel preamplifier. The noise was recorded using the fourth channel of the recorder, via a Rion UC-57 microphone and a Rion NH-22 preamplifier. The microphone was mounted on a tripod approximately 1.2 metres above the floor, and at least 1.5 metres away from a wall.

The Rion DA-20 recorder was set to run in automatic triggering mode. In this mode, the recorder was programmed to start and continuously record 5 minutes of noise and vibration signals when a pre-set vibration trigger level of 0.02 m/s^2 was reached. In order to avoid the recorder being triggered by the residents' movement or other activities, the residents were asked to activate the triggering mode at the time when they went to sleep at night, and to stop the recording mode when they rose the next morning. As such, the Rion DA-20 Recorder mainly recorded the indoor noise and vibration levels at night time.

The Sony PC 204 Digital Recorder was installed in the garage outside the house to record three channels of vibration signals and one channel of noise. Again, three of the four channels of the recorder were used to measure the vibration level. However, unlike the vibration measurement inside the house, three B&K accelerometers were mounted on three blocks, each measuring the z-direction (vertical) vibration only. The sound pressure levels were recorded onto the fourth channel of the recorder via a Brüel and Kjær Type 4155 microphone and Brüel and Kjær Type 2639 microphone preamplifier. The microphone was mounted on a tripod approximately 1.2 metres above the floor.

The Sony PC 204 Digital Recorder was running in manual logging mode, which required the resident to physically activate the recorder whenever a train was passing by and the vibration and noise from the train were considered intrusive. The resident was also requested to make a written record of the date and time of the event and a description of the train.

All vibration measurement channels of both the Rion DA-20 and Sony PC 204 were calibrated with a Brüel and Kjær Type 4291 accelerometer calibrator before the measurement. A calibration signal of 10 mm/s^2 peak (7.07 mm/s^2 RMS) at 79.6 Hz generated by the calibrator was recorded into each vibration channel. A calibration signal of 94 dB at 1 kHz was recorded on the audio channel before the measurement. All subsequent analysis was made with reference to these recorded calibration signals.

MONITORING LOCATIONS

A total of four vibration monitoring locations and two noise monitoring locations were used for gathering data during this measurement, as shown in Fig. 1. One vibration measurement and one noise measurement were located in the large, open lounge area inside the house, using the Rion DA-20 Data Recorder. The three channel (X-Y-Z) accelerometer was mounted on the tiles outside the carpeted lounge area. The microphone for the noise channel was mounted on a tripod approximately 1.2 metres above the carpeted floor inside the lounge, and was at least 1.5 metres from the nearest dividing wall and approximately 1.2 metres below the ceiling. The reason that both the vibration and noise measurements were conducted in/near the lounge area was that the residents indicated that this was the area most affected by rail noise and vibration.

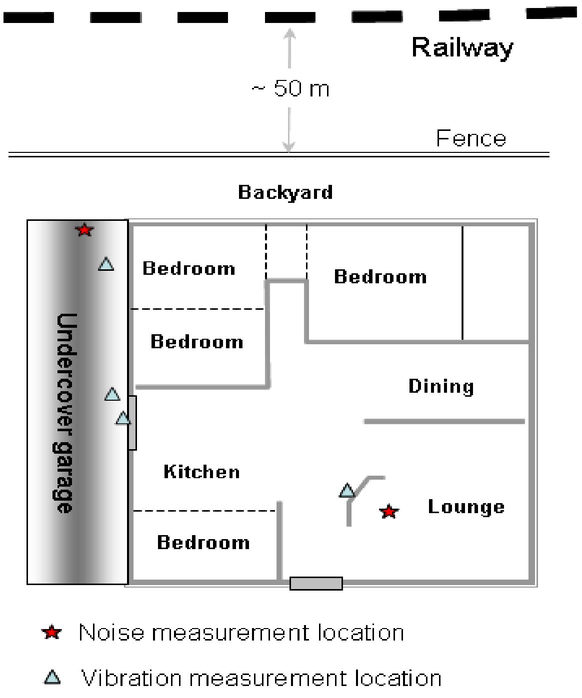

Figure 1. Noise and Vibration Monitoring Locations
(Note: not to scale)

The Sony PC 204 Digital Recorder was positioned in the undercover garage area. Two accelerometers were mounted on the eastern side of the garage floor adjacent to the wall of the house – channel one was in the backyard side of the garage, and channel three was in the middle of the garage near the sliding door. The third accelerometer (channel two) was mounted on top of the sliding door foundation, to pick up the vibration levels on the house structure. The microphone for the noise channel was mounted on a tripod approximately 1.2 metres above the floor in the open backyard side of the garage.

MONITORING RECORDS

Seventy nighttime train events were recorded during the period from 27 March to 13 April 2009 by the indoor recorder. On average, there were about four train passby events a night. However, there could be up to six train passbys on a busy night.

There were 15 train passby events recorded by the manually operated outdoor recorder over the monitoring period. These recorded events were basically in the daytime or evenings. This does not represent the actual number of train passby events in the daytime and evenings of the monitoring period. As this recorder was manually operated by the resident, it is very likely that a large number of train passby events were missed out while the resident was away to work or did not have time to activate the recorder when the rail noise was heard.

ANALYSIS

The analysis of the monitoring data indicated that most train passby events lasted no longer than one minute. Figure 2 shows an example of the measured vibration level inside the house generated during a train passby.

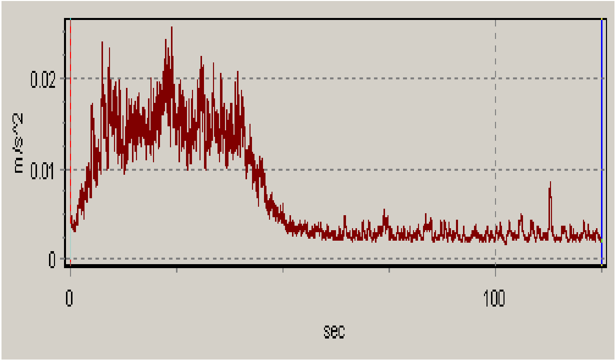

Figure 2. Time history of the vibration level generated by a typical train

The analysis of the data recorded by the Rion DA-20 was performed using Rion DA-20 PA1 software, while the data recorded by the Sony PC 204 were transferred into a Brüel and Kjær Type 2250 Analyser and analysed by using the Brüel and Kjær Type 7820 Evaluator software. One-third octave spectral analysis was performed on the vibration channels over the 1 Hz to 80 Hz range, while the same analysis was conducted for the noise channel over the 6.3 Hz to 20 kHz range.

All recorded noise and vibration data have been analysed and the results and conclusions are based on these analyses. However, because of the amount of data and information, only the noise and vibration levels of several typical trains are presented in the following discussions.

RESULTS

Indoor Vibration Level

The analysis of 70 indoor vibration recordings indicates that all the measured vibration levels generated by the railway inside the house were below the base curve given by AS2670.2: Evaluation of human exposure to whole-body vibration – Continuous and shock-induced vibration in buildings (1-80 Hz). Figure 3 presents typical recordings of vibration levels which clearly demonstrate this finding. According to AS2670.2, vibration below the base curve is not likely to cause human annoyance.

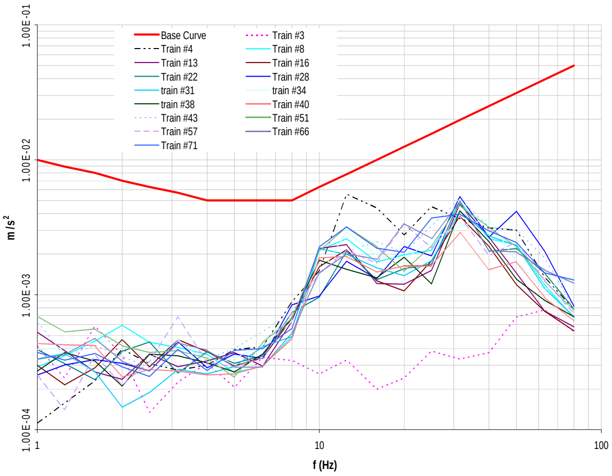

Figure 3. Spectra of indoor vibration generated by trains

Indoor Noise Level

During the time when a train was passing by, the maximum measured noise levels inside the house ranged from 36 dB(A) to 46 dB(A). The calculated two-minute L_{Aeq} level ($L_{Aeq, 2min}$) varied from 30 dB(A) to 41 dB(A). Table 1 presents the maximum instantaneous noise levels and calculated $L_{Aeq, 2min}$ levels for eight typical measured train passby events. The 8-hour nighttime L_{Aeq} levels ($L_{Aeq, 8h}$) were calculated over the period 10pm to 6am based on the $L_{Aeq, 2min}$ level of each train passby event and the total number of train passby events over a night. Assuming that on average there are four train passby events a night, it can be calculated that the average nighttime $L_{Aeq, 8h}$ level generated by trains is in the range 15 to 21 dB(A) inside the house. In the worst case scenario (assuming six train movements a night and all noisy trains), the nighttime $L_{Aeq, 8h}$ level can be up to approximately 26 dB(A) inside the house.

The noise spectra of 16 train passbys measured inside the house are shown in Fig. 4. It is clear that the indoor noise had very strong low-frequency energy in the range from 10 Hz to 100 Hz. Figure 4 also shows that while the A-weighted noise levels were in the range 36 to 46 dB(A), the C-weighted levels were in the range 71 to 78 dB(C). The difference between the A and C-weighted levels was in the range 29 to 35 dB, indicating strong low-frequency content.

Table 1. Indoor noise levels of eight typical train passby events

Train #	$L_{A\ max}$ dB(A)	$L_{Aeq,\ 2min}$ dB(A)
2	43.9	38.6
3	36.1	30.5
8	44.5	40.1
13	45.4	37.8
16	42.3	37.8
22	41.4	35.4
51	45.6	41.4
68	43.4	38.1

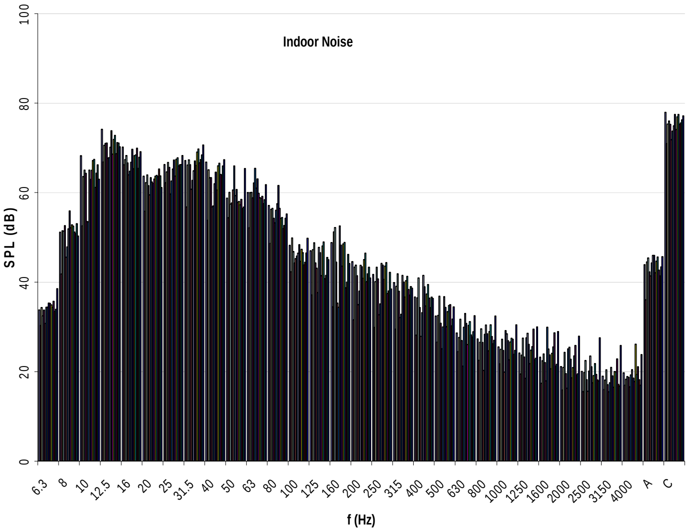

Figure 4. Spectra of indoor noise generated by trains.

Outdoor Vibration Level

The outdoor vibration measurement results also indicated that the vibration levels generated by most trains were below the base curve, which is a basic acceptable vibration level in buildings specified by AS2670.2. However, there were two trains (described as ‘medium’ trains) for which the vibration levels on the garage floor were marginally over the base curve. Figure 5 shows the vibration levels measured by the three accelerometers during one of the ‘medium’ train passbys. Figure 5 also indicates that while the vibration levels at two measured locations on the garage floor (Channel 1 and Channel 3) were marginally over the base curve, the vibration level on the top of the foundation that the sliding door sits on (Channel 2) was still clearly below the base curve. This level may indicate that the vibration level of the building structure generated by the train was still below the base curve.

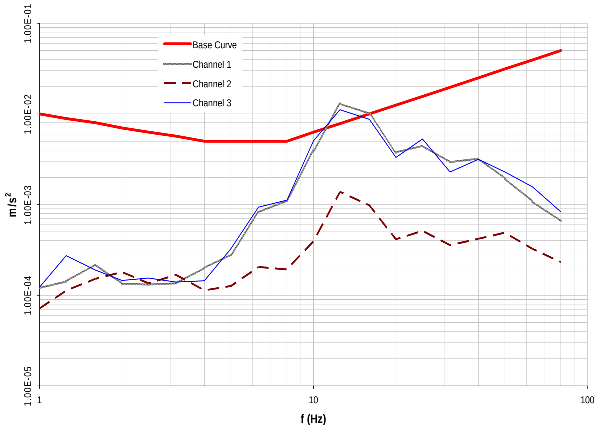

Figure 5. Spectra of outdoor vibration generated by trains

Outdoor Noise level

Unlike the indoor noise measurement, which lasted for five minutes for each train passby event, the period for measuring the outdoor noise was shorter – ranging from 13 seconds to 40 seconds. This was because the outdoor measurement was operated by the residents only when the train noise/vibration was already heard/felt by them. It is understandable that some early parts of the rail noise/vibration passby were missed out due to this procedure.

The measured outdoor noise levels generated by trains are given in Table 2. It can be seen from Table 2 that the maximum A-weighted noise level generated by trains was about 70 dB(A) in the resident's backyard. As the measurement period for each train passby event was short, the $L_{Aeq,\ 2min}$ level for each train passby event can not be calculated. However, the $L_{Aeq,T}$ levels for the measured periods are also listed in Table 2, and these values range from 56 dB(A) to 69 dB(A).

Assuming that the noise generated by the daytime trains is the same as that generated by the nighttime trains, and assuming that the relationship between the $L_{A\ max}$ and $L_{Aeq,\ 2min}$ level of the indoor noise also applies to the outdoor train noise, it can therefore be estimated that the outdoor $L_{Aeq,\ 2min}$ levels should be in the range 51 dB(A) to 65 dB(A). The outdoor nighttime $L_{Aeq,\ 8h}$ levels generated by trains can be estimated to be in the range 42 dB(A) to 50 dB(A) on an average night, and up to 55 dB(A) on a busy night.

Table 2. Outdoor noise levels of eight typical train passby events

Train #	**Measuring time T (s)**	**$L_{Aeq,T}$ dB(A)**	**$L_{A\ max}$ dB(A)**
2	20	65.3	67.4
3	35	68.6	69
4	13	66.7	70.3
5	35	69	70.8
6	18	62.3	67.3
7	18	64.4	66.2
8	40	58.5	61.2
9	16	56	59.3

The outdoor noise spectra are shown in Fig. 6. Compared with Fig. 4, the outdoor noise spectra vary more significantly with different trains. Though very strong low-frequency energy can also be seen with the outdoor noise, the difference between A and C-weighted noise levels is not as high as that with the indoor noise. Here the C-weighted noise levels were only about 11 to 22 dB higher than the A-weighted noise levels. This means that the low-frequency problem outside the house was not as serious as that inside the house.

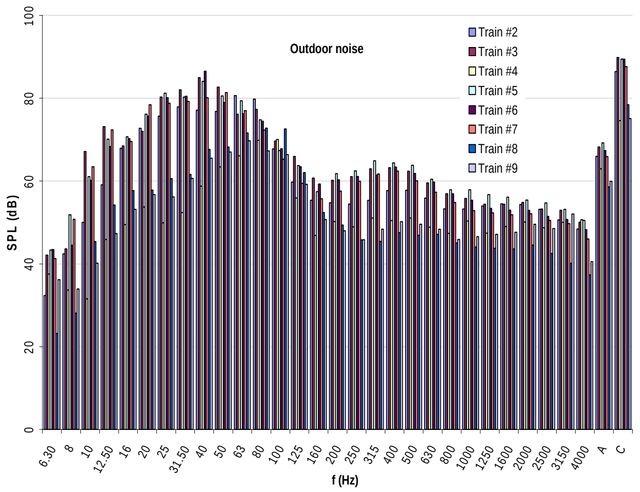

Figure 6. Spectra of outdoor noise generated by trains

DISCUSSIONS AND CONCLUSIONS

The vibration measurement results at both outside and inside locations indicate that the vibration levels generated by trains did not exceed the base curve specified by AS2670.2: *Evaluation of human exposure to whole-body vibration – Continuous and shock-induced vibration in buildings (1-80 Hz).* According to AS2670.2, a vibration level below the base curve is not likely to cause human annoyance. This may indicate that the community's annoyance towards the trains may not be caused by the vibration generated by the trains.

The maximum noise levels for train passbys were measured in the range 36 to 46 dB(A) in the lounge area inside the house, and 56 to 69 dB(A) in the backyard of the residence. As on average there were about four train passby events a night, the nighttime $L_{Aeq,\ 8h}$ levels can be estimated to be about 15 to 21 dB(A), up to a maximum of about 26dB(A) inside the house. These indoor noise levels would be well within the World Health Organisation (WHO) guideline level of 35dB(A) for indoor living areas during the daytime or evening. Rail noise levels in this range are usually considered acceptable, and should not cause community concerns or complaints.

The spectral analysis however indicates a low-frequency problem with the rail noise, especially inside the house. Figure 7 compares an indoor train noise spectrum to an outdoor train noise spectrum. It can be seen from this figure that while the A-weighted noise level was reduced by about 25 dB by the building structure, the C-weighted noise level was only reduced by about 12 dB. Figure 7 also indicates that while the noise energy in the high frequency range was significantly attenuated, the attenuation in the low-frequency range was small. As a result, the low-frequency problem became more serious inside the house.

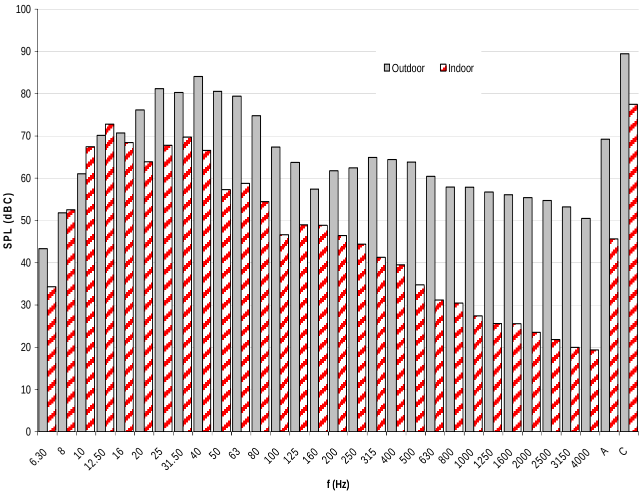

Figure 7. Comparison of spectra of the indoor train noise and outdoor train noise

It can also be seen from Fig. 7 that the C-weighted noise level was about 77 dB(C) inside the lounge area during the train passby. This level is significantly higher than the low-frequency criteria proposed by George and Hessler (2004) for industrial noise measured outdoors but close to residential structures. This may explain why such low-frequency noise from the railway operation causes concerns and complaints from the neighbouring community.

FUTURE STUDIES

This study is a preliminary investigation of a low-frequency environmental noise problem that has harassed the local community for years. The DEC Noise Branch has identified the following future studies that are required to tackle and possibly solve this problem.

Although low-frequency noise, or infrasound, is currently not specifically regulated in Western Australia, it has been reported that it can be a source of complaint. Because human ears are less sensitive to low frequencies, the low-frequency noise is normally ‘felt’ more than heard, and is then easily confused with vibration. Some countries, especially the European countries, are trying to regulate low-frequency noise (Leventhall and Benton 2003). Investigation to properly regulate the low-frequency problem in Westen Australia is required.

Further analyses of the noise spectra indicate that at some low frequencies, such as 10Hz and 12.5Hz bands, the noise level inside the house was higher than that outside the house. This means that this noise energy was increased during transmission into the house. The reason for this noise amplification can be either airborne noise or regenerated noise resulting from ground vibration.

This energy can enter the house and activate low-frequency acoustic modes. These acoustic modes depend on the shape and size of the room, but generally require a large room. As the inside noise was only measured in the lounge area, which is the largest space inside the house (and may support low frequency acoustic modes), it is not clear whether the same noise levels would have been obtained in the smaller rooms. A further study of the indoor rail noise would be needed to verify this acoustic mode theory. The results of the acoustic modes investigation may be able to provide useful information as to whether the problem is confined to large rooms, or whether it is present in all rooms; and for reducing low-frequency rail noise problems inside residential buildings.

It was identified by the resident that the lounge is the most annoying area. It can be seen from Fig. 1 that the lounge area is located at the front of the house, which is farthest away from the railway track. From the noise transmission theory, it is normally expected that the rail noise transmitted into this area of the house should be less, instead of more than other areas. Higher annoyance in this area may support the acoustic mode theory for the low-frequency problem in this area.

Further study of the low frequency noise path from the railway to the rooms may be able to reveal whether the low frequency noise inside the rooms is primarily airborne or groundborne. The results of this study should be able to provide information or guidance as to how to reduce the low-frequency noise transmition into residential houses along railway tracks.

The DEC Noise Branch put a request for further rail noise monitoring to the resident on 6 June 2009. Unfortunately, the residents had sold the house since the last noise and vibration monitoring period. Further study of the indoor rail noise will therefore depend on the participation of other residents in the area.

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