

Characteristics of vehicles producing excessive noise and ground-borne vibration – Phase 1

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CHARACTERISTICS OF VEHICLES PRODUCING EXCESSIVE NOISE AND GROUND BORNE VIBRATION – PHASE 1

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Executive summary

This research was commissioned by the Transport Research Foundation as part of the self-funded research programme. It is recognised that almost always it is the average noise level on roads and highways that is the subject of attention because it has been directly linked to noise annoyance caused to residents. However, an alternative approach in examining nuisance is to consider the noise caused by the noisiest vehicles or those producing the highest vibration levels. Noisy vehicles can have a very wide footprint and can cause widespread disturbance. Reducing maximum levels of noise in residential areas is likely to reduce sleep disturbance which is a major factor affecting overall annoyance.

In the past it has been found that the maximum pass-by noise for the most noisy of vehicles can be 6-8 dB(A) above the average for the sample. It is therefore useful to consider the types of vehicle that make excessive noise or produce relatively high levels of vibration and their condition and to reach some conclusions on how best to reduce the problem.

The proposed programme of research addresses this issue by collecting and analysing data on excessively noisy vehicles. This will be useful for directing policy on the reduction of excessive noise levels. For example, targeting vehicles with faulty exhausts or HGVs with loose loads.

Measurements were carried out at two sites on a busy dual carriageway road (A34) carrying a high percentage of heavy lorries. The aim was to collect sufficient information on light, medium heavy and heavy vehicles over a period of two days at each site.

It was the intention to collect information on the noise and vibration produced by vehicles under normal operating conditions and not when the vehicle is being driven in an aggressive manner e.g. under harsh acceleration. Sites were found on essentially flat derestricted sections where vehicles were freely moving. Measurements were taken in lay-bys separated from the main carriageway by an island which afforded protection from fast moving traffic on the main carriageway. The first site (Site 1) was on the northbound section of the Newbury by-pass just south of the junction with the A4. Site 2 was on the southbound section of the A34 near Whitchurch. At this site there was a significant crack across the carriageway opposite the measurement point. It was considered this was sufficient to excite significant ground borne vibration and body rattle noise.

At both sites approaching vehicle speeds were obtained with a laser speed meter. Video cameras were set up to capture images of passing vehicles in order to identify possible noise sources. One camera was mounted at a height of approximately 4m to obtain a view of the load carried by the HGVs and a lower camera at a height of 1.5m was used to obtain images of the rear of the vehicle to obtain information on the number plate, exhaust pipes and tyres. At both sites a microphone was set up at a height of 1.2m and placed approximately 7.5 m from the centre of the nearside lane. This was used to record the maximum A-weighted noise level and the corresponding third-octave band spectra of the selected vehicles. In addition, at Site 2 the maximum vertical and horizontal particle velocity in mm/s (a measure of vibration amplitude) was obtained from a geophone attached to the road surface at a distance of 8 m from the centre of the lane containing the irregularity.

The analysis has shown that body rattle noise produced on both a relatively smooth and an uneven road surface is likely to be the cause of most excessive noise. Exhaust noise is another relatively common cause. Air turbulence produced noise in some cases by causing loose covers and securing straps to vibrate and flap. These sources of noise occurred over a wide range of frequencies.

The age of the vehicles appears to be an important factor in some cases both because vehicle noise emissions standards have imposed lower noise limits in recent years and also because a worn engine / exhaust system is likely to emit more noise than a new one.

Vehicle transporters were frequently identified as relatively noisy and an examination of the spectra indicates the importance of body rattle noise for these vehicles. The recorded images suggest a number of possible sources on the trailer but further work is recommended before definite conclusions are reached.

The highest levels of vibration were recorded for the heaviest category of truck, as would be expected. The rear axles produced the highest vibration levels and heavily laden older vehicles were found to produce relatively high vibrations levels. The type of suspension may be a factor too: newer suspensions types incorporate air springs while older vehicles are fitted with steel leaf springs. The latter are more likely to produce higher dynamic loading on the road pavement when unladen and hence generate more vibration. However, both systems have the potential to produce high dynamic loads and hence vibration if shock absorbers are defective.

By establishing the causes of excessive noise and tackling the few vehicles that are a problem could provide a relatively low cost way of reducing noise disturbance. This could provide a powerful addition to the control measures traditionally used to combat noise disturbance.

It is proposed that in a further phase of the project the noise from light vehicles will be examined on a road with fewer lorries than the A34. It was found that because of the high percentage of trucks in the traffic flow it was not possible to obtain a sufficient sample of light vehicles which were uncontaminated by the noise from trucks on the opposite carriageway. It is also proposed to measure the vibration produced on a lower speed road. This will cover the case of vehicles travelling over a large irregularity or traffic calming device where a significant vertical deflection is involved. On high speed roads such as the A34 it is difficult to find significant irregularities due to the need to maintain a safe road surface.

1 Introduction

Nuisance has been related to both average noise levels but also the number of noisy events and maximum levels. Noisy vehicles can have a very wide footprint and can cause widespread annoyance. An example cited at a recent UN-ECE vehicle noise meeting was that a single motorcyclist riding an excessively noisy machine was alleged to have woken up an entire town in Sweden. Reducing maximum levels of noise in residential areas is likely to reduce sleep disturbance (WHO, 2001).

As an illustration the range of maximum pass-by noise levels that can be expected from a random sample of light, medium heavy and heavy vehicles travelling on a smooth surface at constant speed is high. It can often be observed that within a vehicle category the range at a given speed can be large ranging from 6 to 8 dB(A).

The proposed programme of research addresses this problem by collecting and analysing data on excessively noisy vehicles from which priorities for action can be established. This will be useful for directing policy on the reduction of excessive noise levels. For example, targeting vehicles with faulty exhausts or HGVs with loose loads.

Ground borne vibration levels produced by passing heavy vehicles will also be recorded as this is known to cause significant annoyance in some circumstances. Unlike noise, once ground-borne vibration exceeds the perception level, serious disturbance often results as occupants fear that their property will be damaged. In addition, amplification often occurs on suspended wooden floors leading to higher levels being experienced in bedrooms.

Although numerous case studies of vibration disturbance have been carried out over many years it has not been possible with limited resources to examine vehicle factors that contribute to the level of this disturbance. The proposed project will be innovative in investigating such factors for the first time and should lead to new insights into the causal mechanisms involved.

This report describes measurements at two sites on a busy dual carriageway road (A34) with a heavy lorry flow. The aim was to collect sufficient information on the three categories of vehicles over two days at each site. These categories were identical to those described in the Harmonoise traffic noise model (Watts, 2005):

- Category 1 - Light vehicles and vans with 2 wheels on the rear axle
- Category 2 - 2-axle medium heavy goods vehicles, buses and coaches with 4 wheels on the rear axle
- Category 3 – 3 or more axle heavy vehicles

2 Methodology

It was the intention to collect information on the noise and vibration produced by vehicles under normal operating conditions and not when the vehicle is being driven in an aggressive manner e.g. under harsh acceleration. The main reason for this is that it is the vehicle characteristics and not the manner in which the vehicle is being operated that is the main focus of the proposed research. There is a case for examining the irresponsible use of motor vehicles but the methodology adopted would differ to some degree from the approach proposed here.

Sites were found alongside busy roads where there was a lay by separated from the main carriageway by an island. This type of site layout enabled the study team to work in a safe location but also in close proximity and with an unobstructed view of the main traffic stream. The first site (Site 1) was on the northbound section of the Newbury by-pass just south of the junction with the A4. The surface was in good condition (porous asphalt wearing coarse) and the open nature of the site allowed freely moving vehicles to be selected from the traffic stream. In this way it was expected to reduce the influence on recorded noise of other vehicles travelling on the carriageway. A view of the site is given in Figure 2.1. The cameras can be seen in the foreground and on top of the mobile laboratory. The

microphone stand is just beyond the nearest camera and appears just to the right of the mobile laboratory.



Figure 2.1: View of measurement set up at Site 1

Site 2 was on the southbound section of the A34 near Whitchurch. The layout was similar to Site 1 with an island protecting the operators and an unobstructed view of approaching vehicles. The wearing course of the road surface was hot rolled asphalt (HRA). At this site there was a significant crack across the carriageway opposite the measurement point. It was considered this was sufficient to excite significant ground borne vibration and body rattle noise. A view of the site is given in Figure 2.2. The microphone stand and geophone can be seen in front of the mobile laboratory



Figure 2.2: View of measurement set up at Site 2

At both sites approaching vehicle speeds were obtained with a laser speed meter. The operator aimed the laser speed meter while seated in the back of the mobile laboratory. The video cameras were set up to capture images of passing vehicles in order to identify possible noise sources. One camera was mounted at a height of approximately 4m to obtain a view of the load carried by the HGVs and a lower camera at a height of 1.5m was used to obtain images of the rear of the vehicle to obtain information on the number plate, exhaust pipes and tyres.

At both sites a microphone was set up at a height of 1.2m and placed approximately 7.5 m from the centre of the nearside lane. This was used to record the maximum A-weighted noise level and the corresponding third-octave band spectra of the selected vehicles. For this purpose a Bruel and Kjaer third octave real time analyser was used (B&K 2144). A DAT tape recorder was employed to provide a continuous sound record.

In addition, at Site 2 the maximum vertical and horizontal particle velocity in mm/s (a measure of vibration amplitude) was obtained from a geophone attached to the road surface at a distance of 8 m from the centre of the lane containing the irregularity. A view of the geophone array is given in Figure 2.3. Figure 2.4 shows the irregularity in the road that gave rise to significant ground-borne vibration that could be observed above background levels.



Figure 2.3: Geophone array mounted on the road surface with Plaster of Paris



Figure 2.4: Irregularity in road surface at Site 2

3 Results

The results are given separately for Site 1 and Site 2. The analysis at Site 1 is confined to the analysis of the noise and image data while at Site 2 vibration data were also collected for Category 2 and Category 3 vehicles. Vibration levels for light vehicles were not recorded as it was clear these were producing insignificant levels of vibration. Vehicle age data and engine capacity were obtained from DVLA using the recorded vehicle registration numbers. In a few cases the registration number was incomplete and details could not be found by DVLA.

3.1 Site 1 on A34 near Newbury

3.1.1 Light vehicles (Category 1)

Figure 3.1 shows the scatterplot of maximum A-weighted pass-by noise levels against the logarithm of speed. The regression line has been added together with the line at 2 standard deviations above the regression line. Using normal (Gaussian) statistics it would be expected that approximately 2.3% of vehicles will exceed this line. With 219 vehicles in the sample the expected number is 5 vehicles. In Figure 3.1 it can be seen that 3 vehicles were above the line.

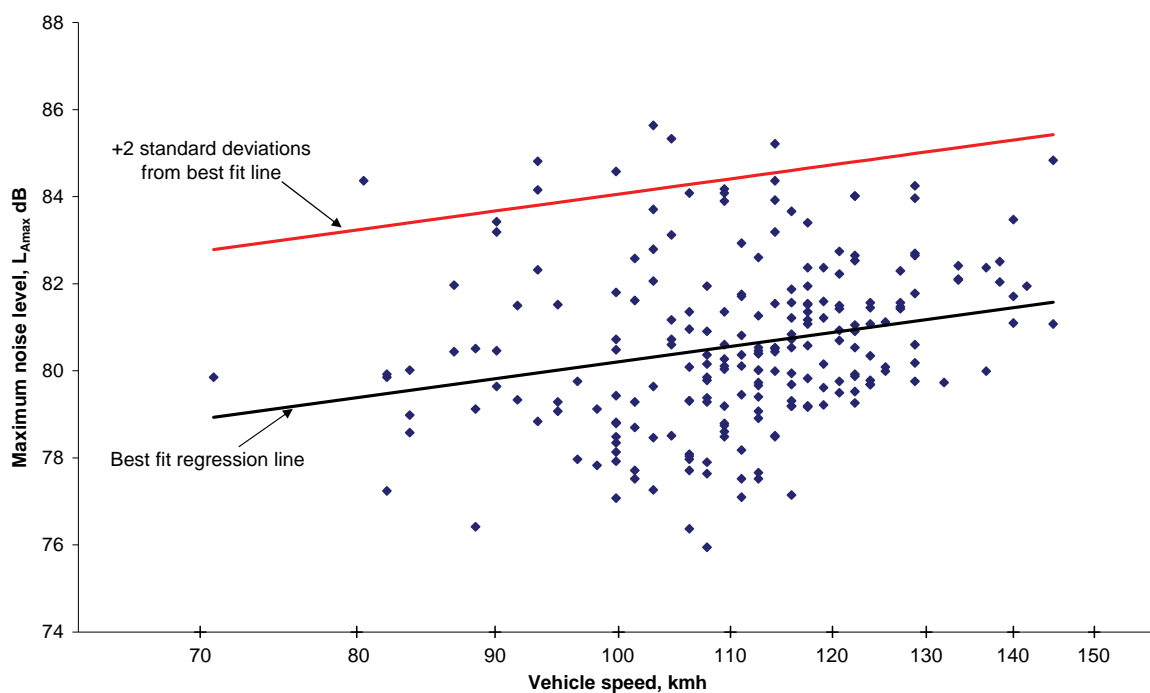


Figure 3.1: Category 1 (light vehicles) at Site 1

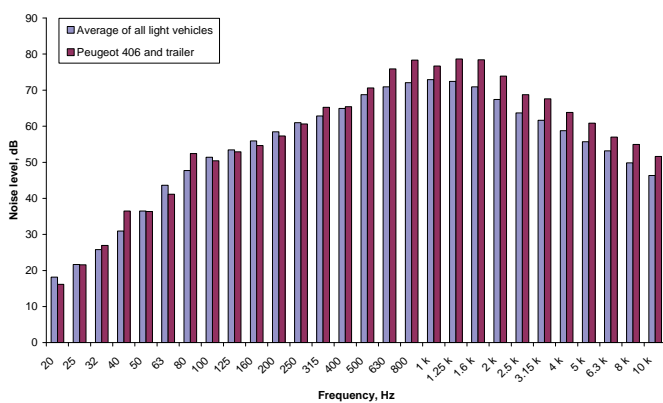
Table 3.1 tabulates in order of maximum recorded noise level, the descriptions of these relatively “noisy” vehicles obtained from the video records.

Table 3.1: Noisy category 1 vehicles (light vehicles)

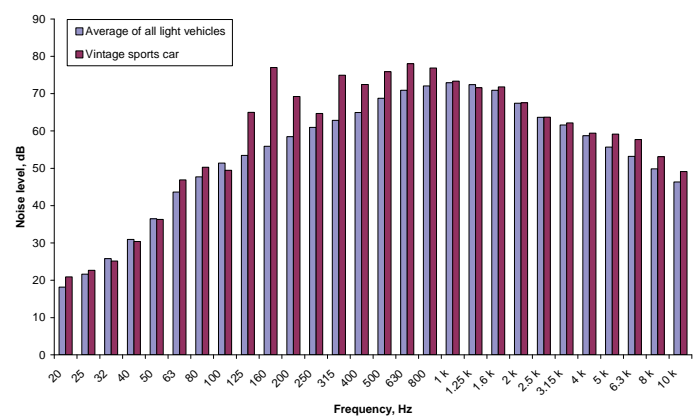
Description	Age	Possible source of noise
Two-seater vintage sports car, open topped, double exhaust.	N/K	Age, exhaust
Medium size saloon car in good condition hauling single axle metal framed trailer in poor condition, dirt bike strapped to trailer	6 yr	Trailer
Old SUV with single axle trailer	18 yr	Age, trailer

The following are the third octave spectra captured at the maximum A-weighted level. For comparison in each graph the average levels across all sampled vehicles in Category 1 are also given.

(a) Saloon car and trailer



(b) Vintage sports car



(c) Old SUV and trailer

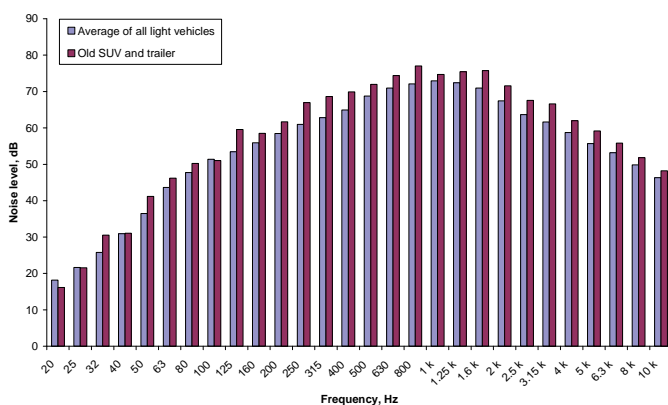


Figure 3.2: A-weighted spectra for light vehicles captured at the maximum A-weighted level

It can be seen in Figure 3.2 (a) that in the case of the saloon car towing the trailer there is an excess of noise above 630 Hz. This is consistent with rattle noises from the relatively old trailer. For the vintage sports car (Figure 3.2(b)) there is tonal noise around 160Hz. This is likely to be exhaust noise resulting from harmonics of the fundamental firing frequency of the engine.

Figure 3.2(c) shows that, for the SUV and trailer, the noise levels are generally higher than the average for a broad range of frequencies. This indicates that the main sources of noise on the vehicle, i.e. engine, exhaust, rolling noise, are all producing higher noise levels than the average vehicle in the sample. SUVs are generally noisier than saloon cars both in terms of propulsion noise and rolling noise. The fact that it was relatively old is also considered to be a factor. The trailer would also have produced additional noise especially rolling and rattle noises.

3.1.2 Medium heavy vehicles (Category 2)

Figure 3.3 shows the scatterplot of maximum A-weighted pass-by noise levels for category 2 vehicles against the logarithm of speed. The regression line has been added and the line at 2 standard deviations above the regression line. Using normal statistics it would be expected that approximately 2.3% of vehicles will fall above this line. With 115 vehicles in the sample the expected number is 3 vehicles. In Figure 3.3 it can be seen that in fact 3 vehicles gave noise levels that were above the line.

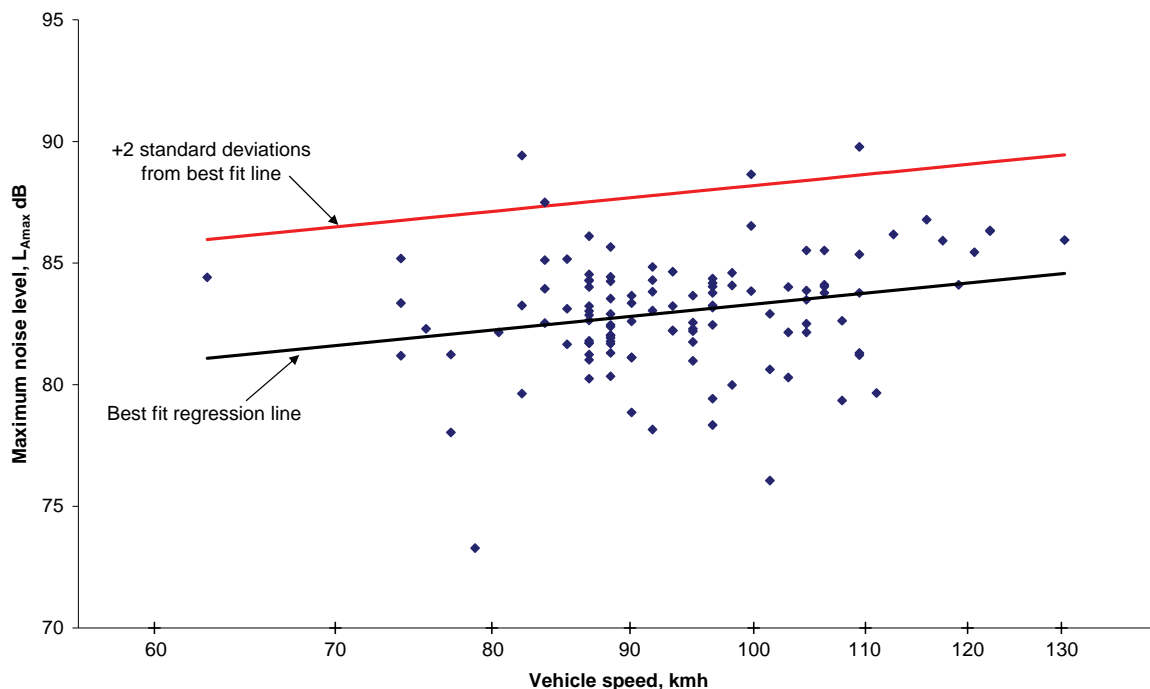


Figure 3.3: Category 2 (medium heavy vehicles) at Site 1

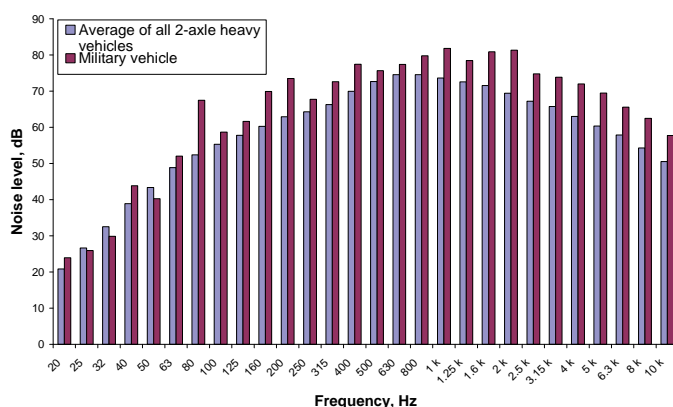
Table 3.2 lists the descriptions of the vehicles that lay above the line 2 standard deviations from the regression line.

Table 3.2: Noisy category 2 vehicles (Medium heavy vehicles and buses and coaches)

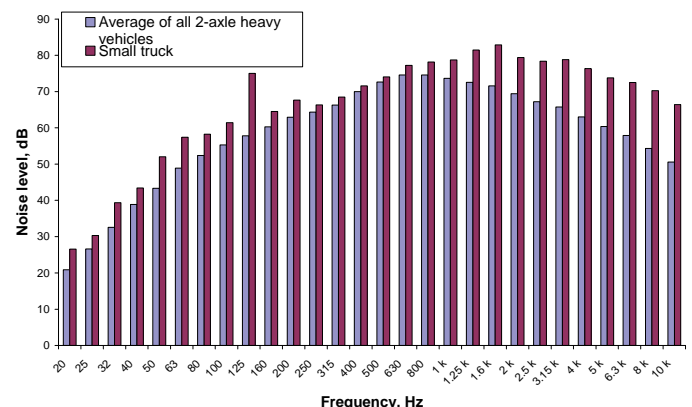
Description	Age	Possible noise sources
Military truck with digging arm on the back.	N/K	Ancillary equipment
Small truck covered with fabric cover	7 yr	Flapping cover
Tipper truck (11.6 litre) carrying tall rusty metal box container	10 yr	Vehicle rattle

The third octave band spectra of these vehicles are given in Figure 3.4. It can be seen that the military vehicle (Figure 3.4 (a)) is excessively noisy across the spectrum. There is a sharp peak at 80 Hz suggesting exhaust noise with possibly a harmonic occurring at 160 Hz. Above 800 Hz there is a general increase suggesting either tyre noise (from possibly off-road tyres with large tread blocks)) or body rattle noise from the mechanical digger. Possible exhaust noise peaks can also be seen in Figure 3.4 (b) and (c) at the lower frequencies. The flapping canvas is probably responsible for the elevated levels shown in Figure 3.4(b). The tone components at 1.25 and 1.6 kHz may result from transmission whine.

(a) Military truck



(b) Small truck with flapping canvas cover



(c) Old truck

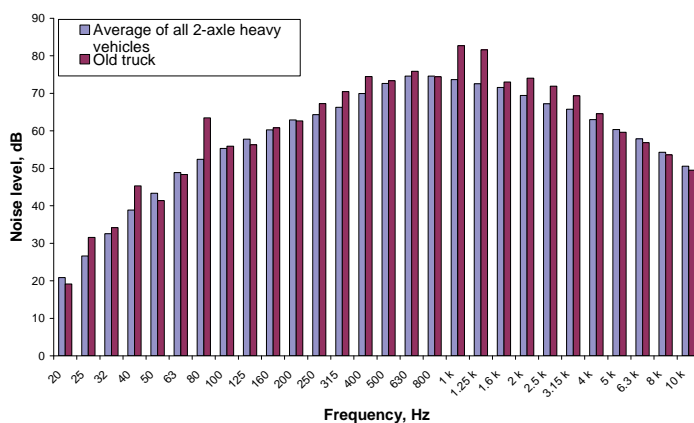


Figure 3.4: A-weighted spectra of medium heavy vehicles captured at the maximum A-weighted level

3.1.3 Heavy vehicles (Category 3)

Figure 3.5 shows the scatterplot of maximum A-weighted pass-by noise levels for category 3 vehicles against the logarithm of speed. The regression line has been added and the line at 2 standard deviations above the regression line. Using normal statistics it would be expected that approximately 2.3% of vehicles will fall above this line. With 280 vehicles in the sample the expected number is 6 vehicles. In Figure 3.3 it can be seen that in fact the noise levels from 7 vehicles are above the line.

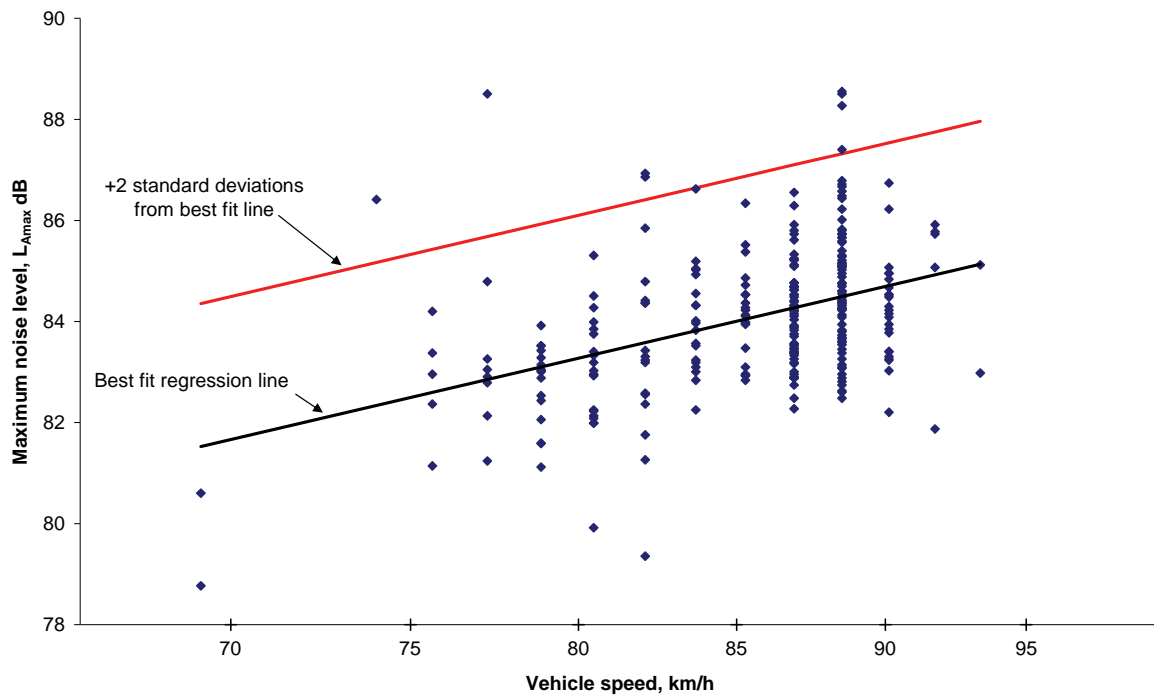


Figure 3.5: Category 3 (heavy vehicles) at Site 1

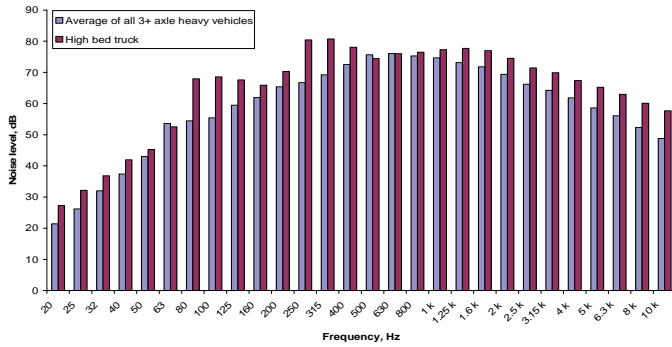
Table 3.3 list the characteristics of the vehicles which lay above the line drawn at 2 standard deviations from the best fit regression line. It can be seen that 6 out of the 7 noisiest vehicles were transporters. In most cases body rattle noises of the trailer was thought most likely to be responsible for these sounds.

Table 3.3: Noisy category 3 vehicles (heavy vehicles with 3 axles or more)

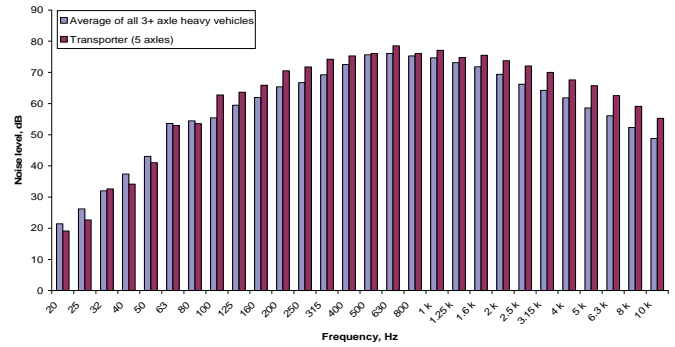
Description	Age	Possible source of noise
High load bed truck (3 axles) with crane attached behind cab.	<1 yr	Ancillary equipment
Car transporter (5 axles, 14.2 litre), unladen	N/K	Slack metal safety fencing on sides of transporter decks
Transporter (8 axles, 14.2 litre), essentially unladen	9 yr	Small amount of construction material
Large vehicle transporter (7 axles, 12.1 litre), unladen	5 yr	Large wheel ramps angled vertically, loose chains on load decks
Transporter (5 axles, 11.9 litre), unladen	3 yr	Slack metal wire fence around load decks
Transporter (5 axles) carrying small digger behind cab, then large steel cage for rest of length	N/K looks old	Load rattling
Heavy vehicle transporter (7 axles, 15.9 litre), loaded with site vehicles	2 yr	Load rattling

The third octave band spectra of these vehicles are given in Figure 3.6. It can be seen in Figure 3.6 (a) that the high load bed truck with 3 axles is noisy at low, mid and high frequencies. The relatively high levels at low and mid frequencies are probably due to engine and exhaust noise while at high frequencies rattle noises are probably responsible. The crane behind the cab would probably be a significant source of rattle noise. The remaining vehicles are all transporters with 4 of the 6 being unladen. Loose chains, safety fences around load beds, ramps are all source of rattle noise. The open frame and lack of streamlining would also contribute to increases in aerodynamic noise though this is thought to be relatively low at speeds around 90 km/h. The effect of these sources is a significant increase in noise levels above 800 Hz as can be seen in all the figures 3.6 (b) to 3.6 (g).

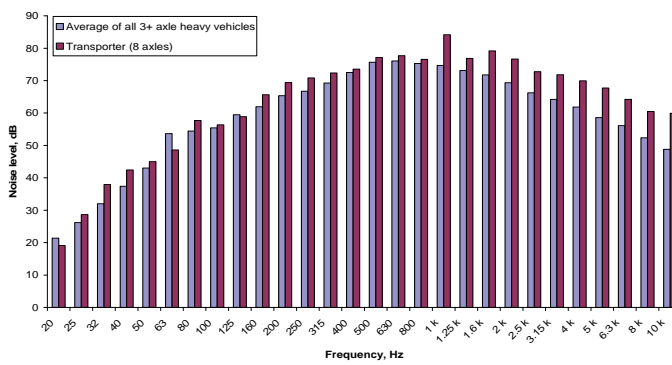
(a) High load bed truck (3 axles)



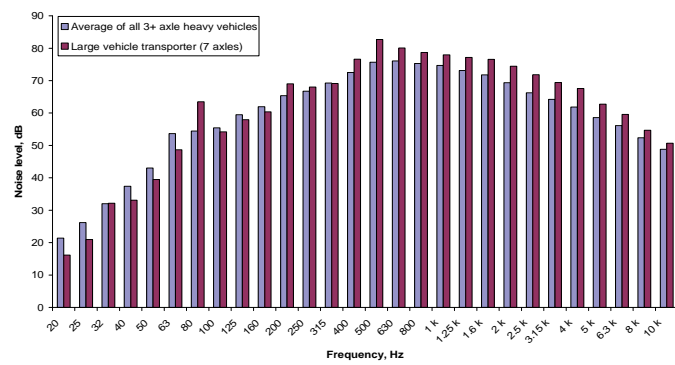
(b) Car transporter (5 axles) unladen



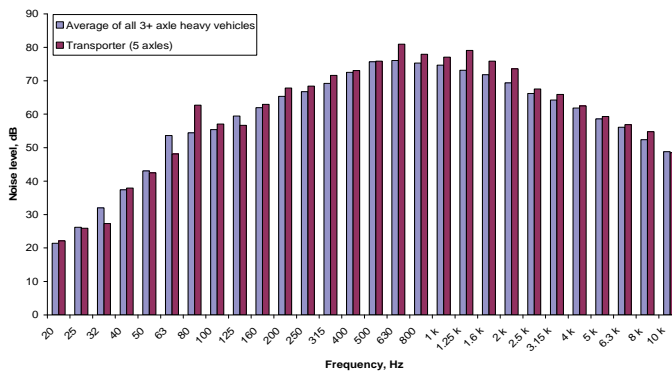
(c) Transporter (8 axles)



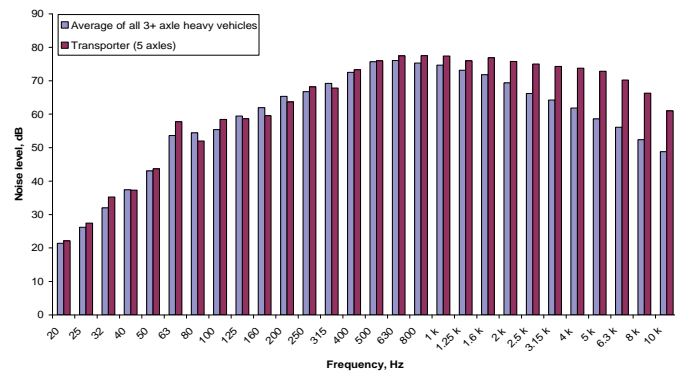
(d) Large vehicle transporter (7 axles)



(e) Transporter (5 axles)



(f) Transporter (5 axles)



(g) Heavy vehicles transporter (7 axles)

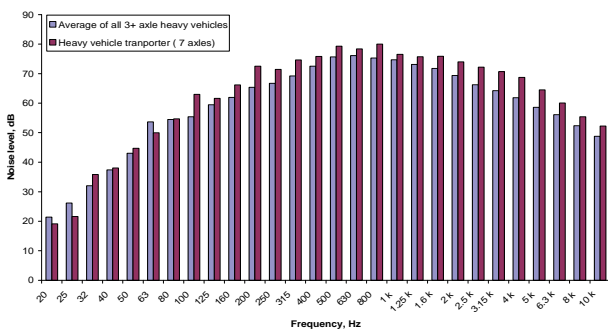


Figure 3.6: A-weighted spectra of heavy vehicles captured at the maximum A-weighted level

3.2 Site 2 on A34 near Whitchurch – noise results

3.2.1 Light vehicles (Category 1)

Figure 3.7 shows the scatterplot of maximum A-weighted pass-by noise levels against the logarithm of speed. The regression line has been added and the line at 2 standard deviations above the regression line. Using normal statistics it would be expected that approximately 2.3% of vehicles will fall above this line. With 114 vehicles in the sample the expected number is 2.6 vehicles. In Figure 3.3 it can be seen that in fact 1 vehicle gave a noise level that is above the line.

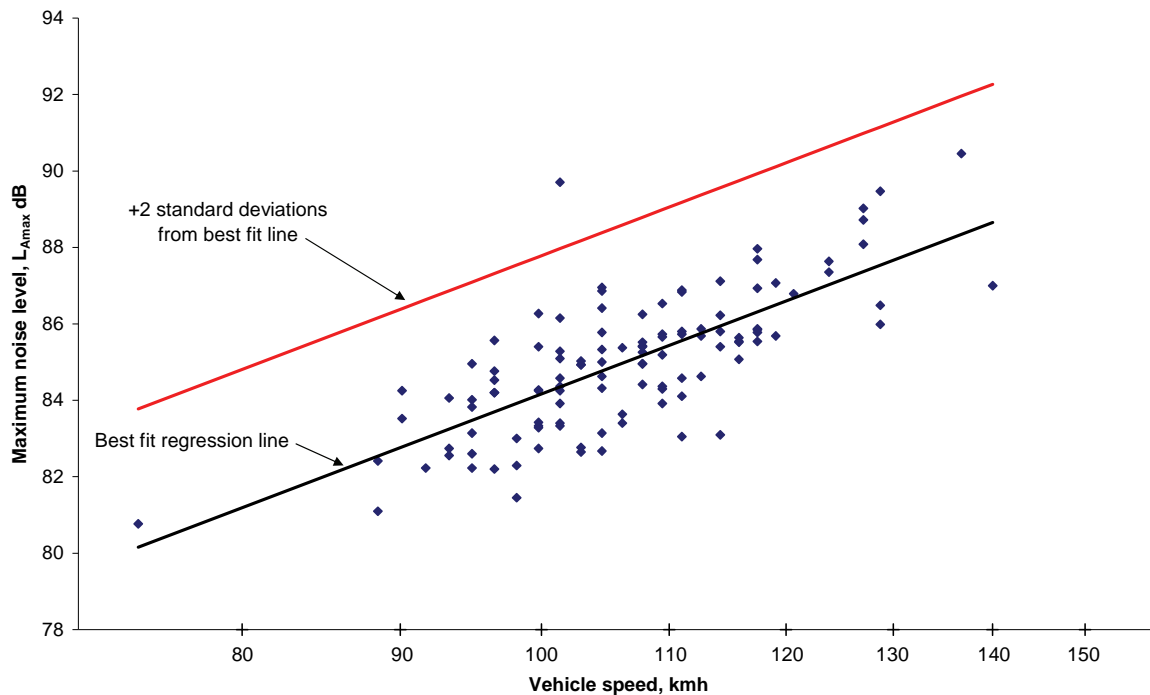


Figure 3.7: Category 1 (light vehicles) at Site 2

This vehicle was a new (2006) saloon car with twin exhaust tail pipes. This may have been a modified vehicle. The third octave band spectra is given in Figure 3.8 where it is compared with the average spectra obtained for category 1 vehicles at this site. It can be seen that the car gave large exceedances above the average at very low frequencies indicating excessive exhaust noise. The high levels above 1.6 kHz is of interest as it is difficult to reconcile with a new vehicle where body rattle noise would not be expected. It is possible that the tyre noise is excessive and this may result from the fitting of special tyres.

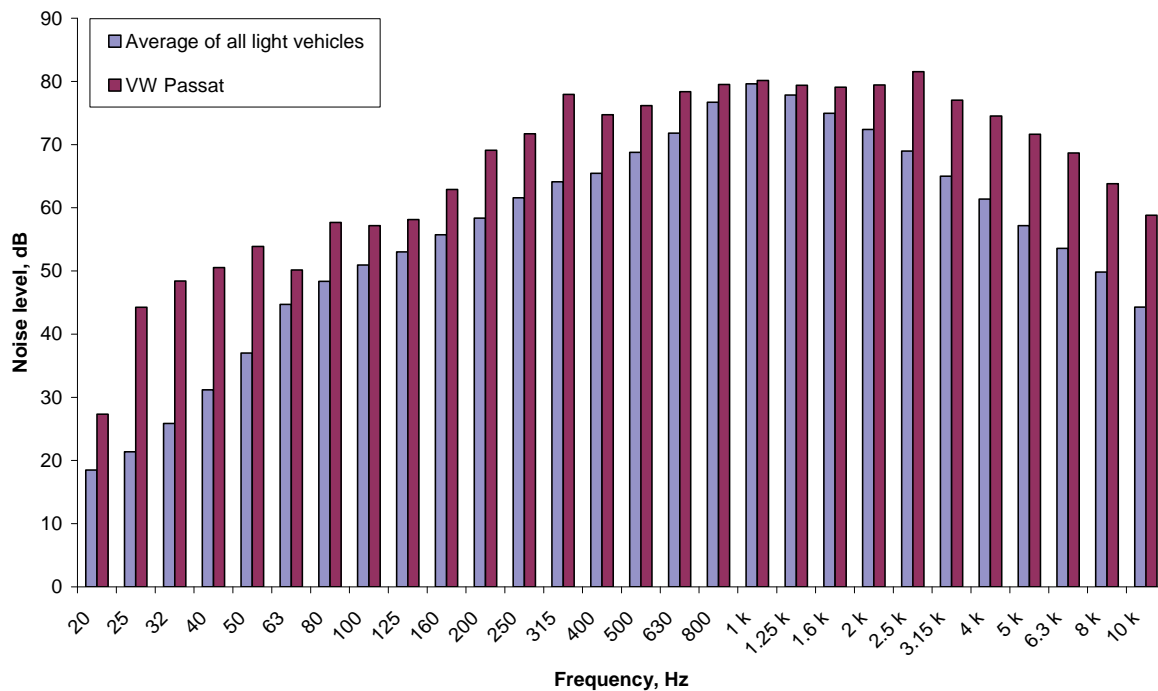


Figure 3.8: A-weighted spectra of a light vehicle captured at the maximum A-weighted level

3.2.2 Medium heavy vehicles (Category 2)

Figure 3.9 shows the scatterplot of maximum A-weighted pass-by noise levels against the logarithm of speed. The regression line has been added and the line at 2 standard deviations above the regression line. Using normal statistics it would be expected that approximately 2.3% of vehicles will fall above this line. With 72 vehicles in the sample the expected number is 1.7(2) vehicles. In Figure 3.9 it can be seen that in fact 2 vehicles lay above the line. The details of these two vehicles is given in Table 3.4.

Table 3.4: Noisy category 2 vehicles (medium heavy vehicles)

Description	Age	Possible source of noise
Mini car transporter (5.9 litre) with 3 cars on, towing trailer with camper van on. Wire safety fencing on sides of decks	1 yr	Wire safety fences on side of decks
HGV recovery truck (11.7 litre), unladen with large crane on back	4 yr	Rattle noise

The third octave band spectra for these vehicles is given in Figure 3.10. It is likely that body rattle noises are responsible for the relatively high noise levels above 800Hz. In the case of the HGV recovery vehicle there is a relatively sharp peak at around 630 Hz. This could be the result of a noisy driveline e.g. an axle whine where differential gears or bearings are worn.

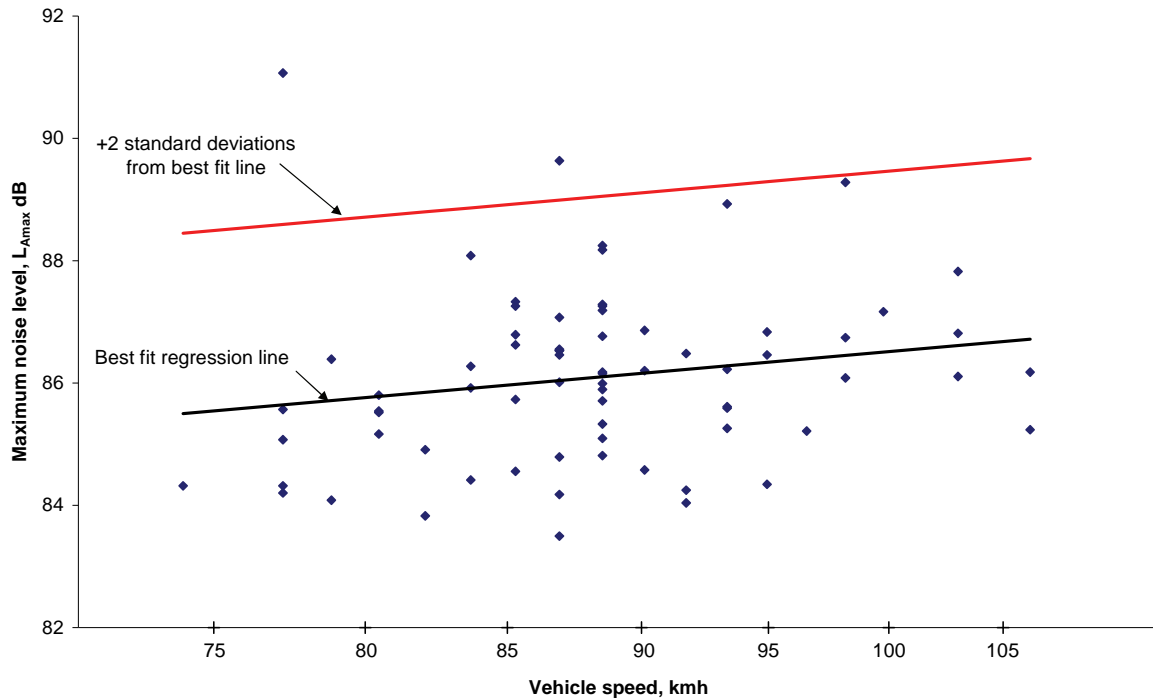
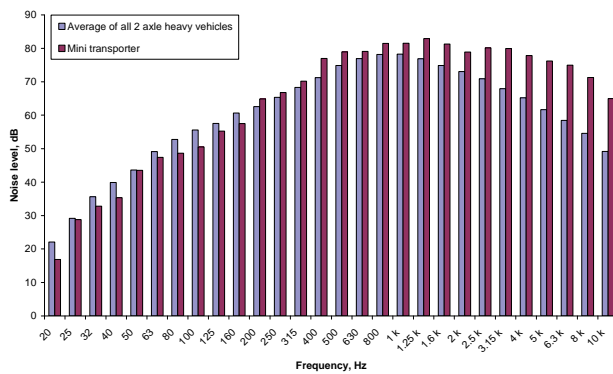


Figure 3.9: Category 2 (medium heavy vehicles) at Site 2

(a) Mini-transporter with trailer



(b) HGV recovery vehicle

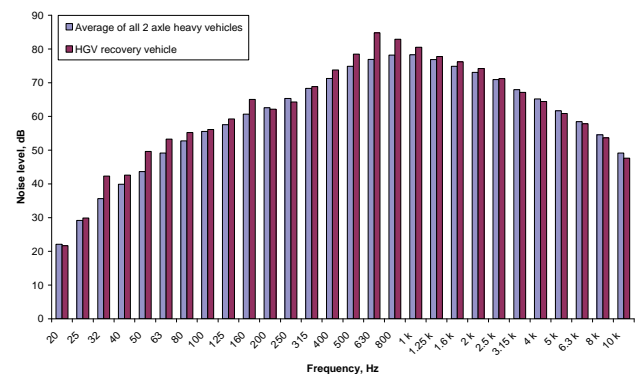


Figure 3.10: A-weighted spectra of medium heavy vehicles captured at the maximum A-weighted level

3.2.3 Heavy vehicles (Category 3)

Figure 3.11 shows the scatterplot of maximum A-weighted pass-by noise levels against the logarithm of speed. The regression line has been added and the line at 2 standard deviations above the regression line. Using normal statistics it would be expected that approximately 2.3% of vehicles will fall above this line. With 360 vehicles the expected number is 8 vehicles. In Figure 3.11 it can be seen that in fact 12 vehicles lay above the line. The details of these vehicles are given in Table 3.5.

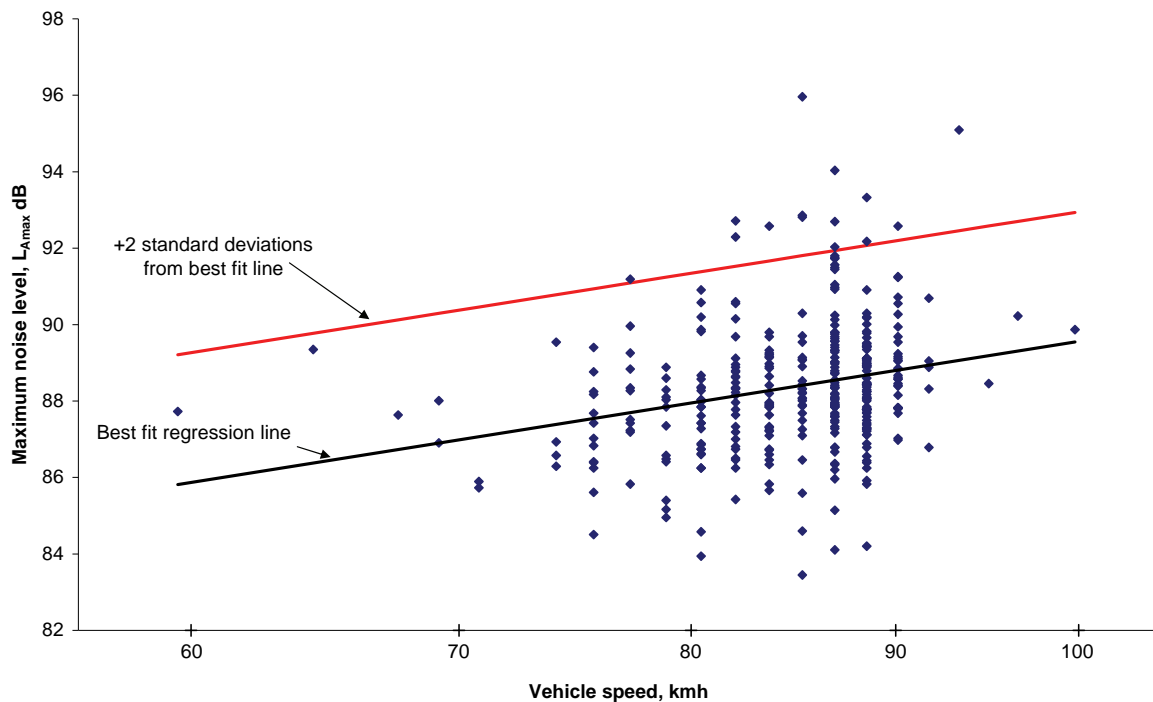


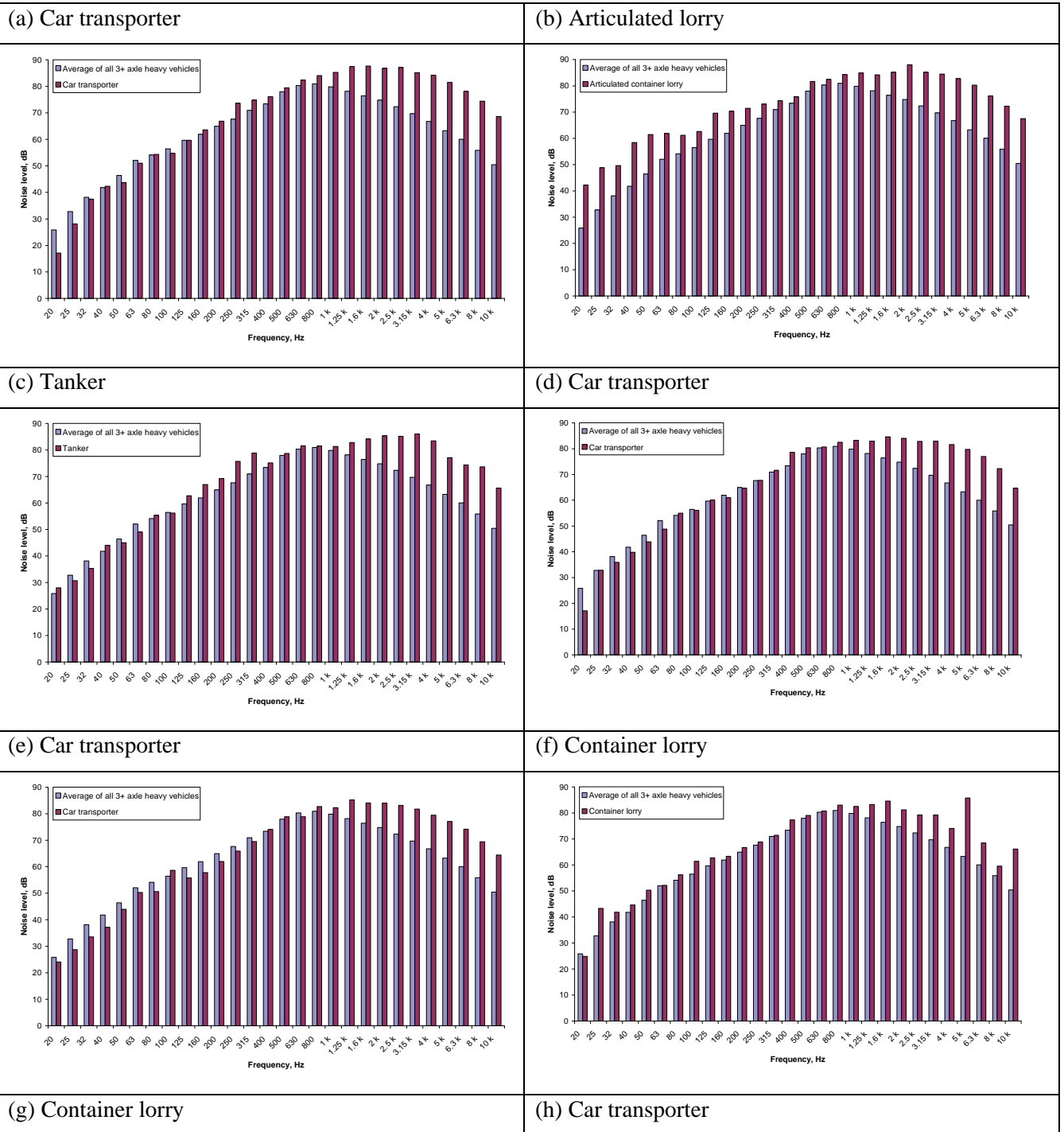
Figure 3.11: Category 3 (heavy vehicles) at Site 2

It can be seen that 5 of the 12 noisy vehicles identified were car or truck transporters. Three were container lorries with short containers.

The third octave band spectra for all these vehicles is given in Figure 3.12. In all cases there are significant increased levels above 1 kHz indicating the importance of body rattle noises. In some cases (b, i, k, and l) significant increases occur at lower frequencies indicating high levels of exhaust or engine noise. In one case (container lorry (f)) there is a strong tonal component at 5 kHz. This could be an aerodynamic edge tone.

Table 3.5: Noisy category 3 vehicles (heavy vehicles)

Description	Age	Source of noise
Car transporter laden with SUVs (5 axles, 11.7 litre)	1 yr	Rattles
Articulated container lorry (5 axle, 15.9 litre)	4 yr	Rattles, exhaust
Tanker with rectangular metal frame around tank (6 axle)	N/K	Rattles
Car transporter part laden (5 axles, 12.1 litre)	1 yr	Rattles
Car transporter fully laden (5 axles, 11.1 litre)	<1 yr	Rattles
Container lorry with 1/2 length container (5 axles, 11.7 litre)	2 yr	Rattles, edge tone
Container lorry with 1/2 length container (6 axles, 10.5 litre)	< 1yr	Rattles
Car transporter part laden (4 axles, 11 litre)	5 yr	Rattles
Heavy vehicle transporter laden with 2 tractor units (6 axles, 12.6 litre)	< 1yr	Rattles, exhaust
Container lorry with 1/2 length container. Container protrudes above cab fairing (5 axle, 12.1 litre)	2 yr	Rattle
Articulated lorry (5 axles). Canvas sides flapping	7 yr	Rattle, exhaust
Articulated lorry (5 axles), rigid container	N/K appeared old	Rattles, exhaust



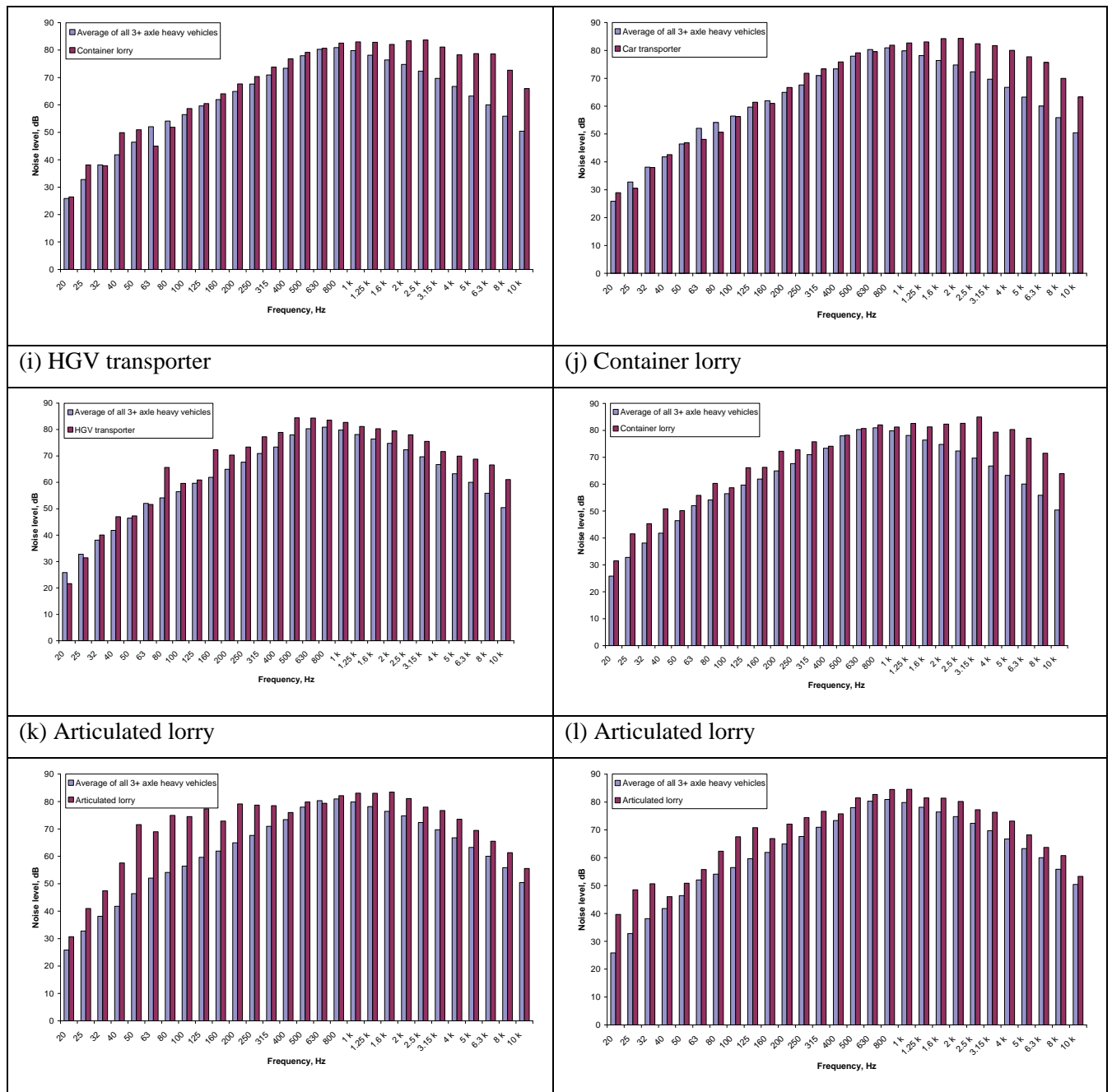


Figure 3.12: A-weighted spectra of heavy vehicles captured at the maximum A-weighted level

3.3 Site 2 on A34 near Whitchurch – vibration results

3.3.1 Medium heavy vehicles (Category 2)

Figure 3.13 shows the maximum component of vertical vibration plotted against speed. In all cases of significant vibrations the vertical component was greater than the radial component and this agrees with previous work (Watts, 1990). It can be seen that the vertical vibration levels did not show any significant variation with speed. In order to obtain a sufficiently large sample of vehicles the criteria was relaxed to 1.5 standard deviations above the mean. With 72 vehicles in the sample the expected

number exceeding 1.5 standard deviations would be 6.7% or 4.8 vehicles. In fact the number observed was 4 vehicles and the details for these vehicles are given in Table 3.6.

Figure 3.14 show the vertical vibration traces for the two vehicles producing the highest vibration levels. In both cases the rear axle produces the greatest vibration level. In the case of the flat bed truck the frequency of vibration is approximately 11.8 Hz (see Figure 3.14(a)) while the corresponding frequency for the truck with canvas sides was 9.1 Hz (see Figure 3.14(b)). These frequencies are within the normal range of frequencies observed at other sites. It corresponds to the wheel hop frequency i.e. the oscillation of the wheels and axle between the vehicles body suspension and the tyres (which act as a damped spring) (Watts and Krylov, 2000).

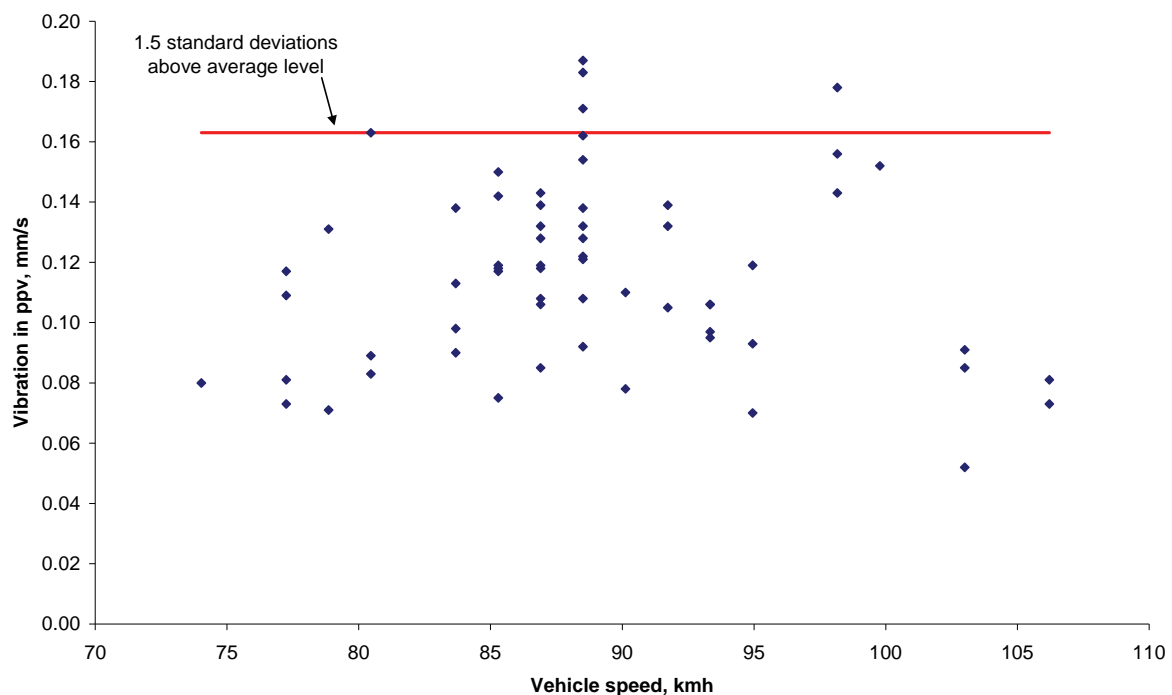
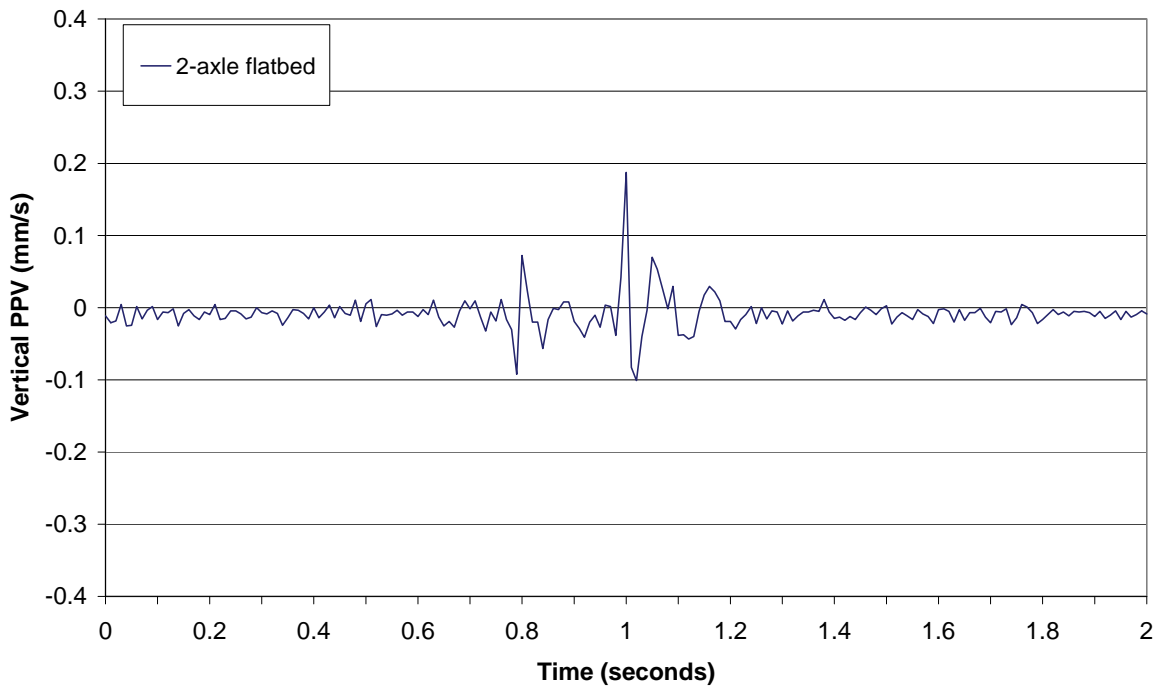


Figure 3.13: Maximum peak particle velocity for category 2 (medium heavy vehicles) at Site 2

Table 3.6: Category 2 vehicles (medium heavy vehicles) producing highest vibration levels

Description	Age	Max. PPV
Flat bed truck with mesh fence protruding above cab	N/K but looked old	0.19
Truck with curtain sides (6.4 litre)	1 yr	0.18
Coach (12 litre)	3 yr	0.18
Drop side truck with loose concrete slabs (5.5 litre)	2 yr	0.17

(a) Flat bed 2-axle truck



(b) 2-axle truck with canvas sides

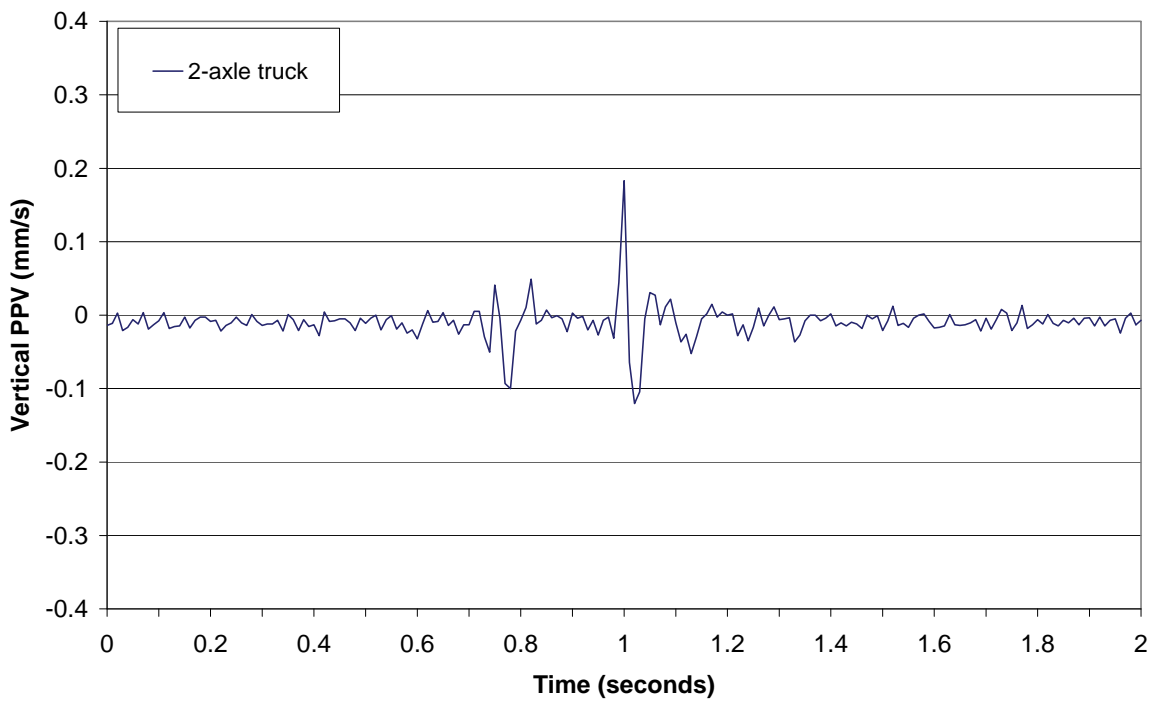


Figure 3.14: Time histories of vertical particle velocity (mm/s)

3.3.2 Heavy vehicles (Category 3)

Figure 3.15 shows the maximum component of vertical vibration plotted against speed. As for 2-axle medium heavy vehicles in all cases of significant vibrations the vertical component was greater than the radial component. Again it can be seen that there is very little variation with speed. With 360 vehicles in the sample the expected number exceeding 2 standard deviations would be 2.3% or 8.3 vehicles. In fact the number observed was 11 vehicles. The details for these vehicles are given in Table 3.7.

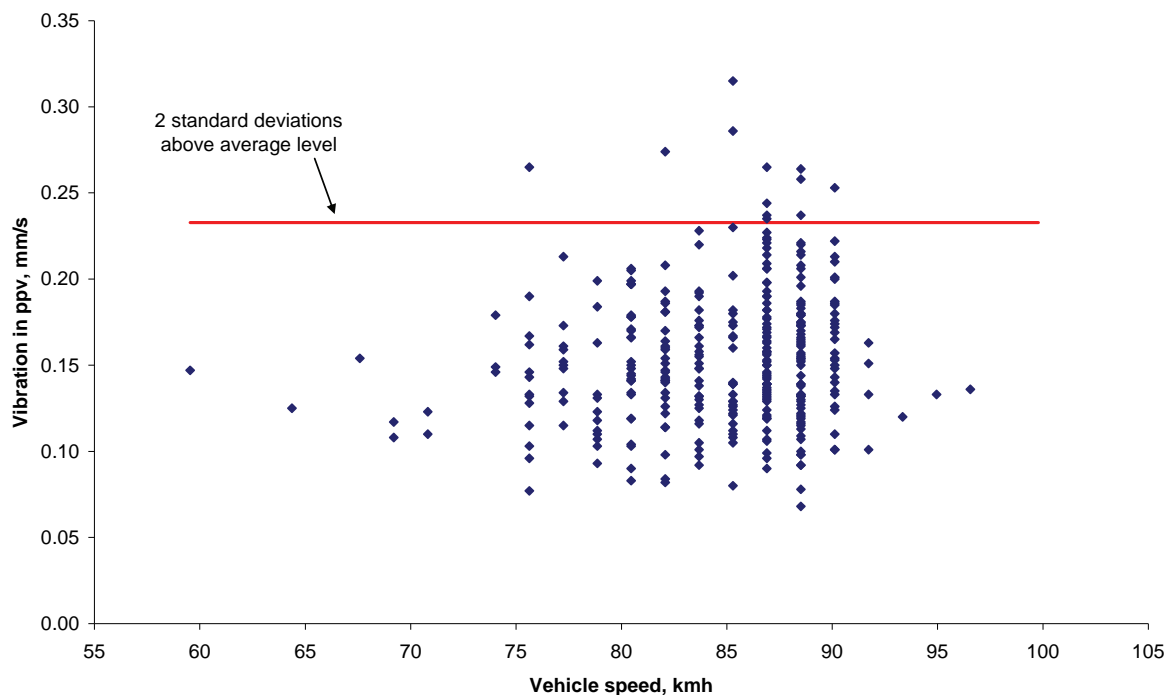


Figure 3.15: Maximum peak particle velocity for category 3 (heavy vehicles) at Site 2

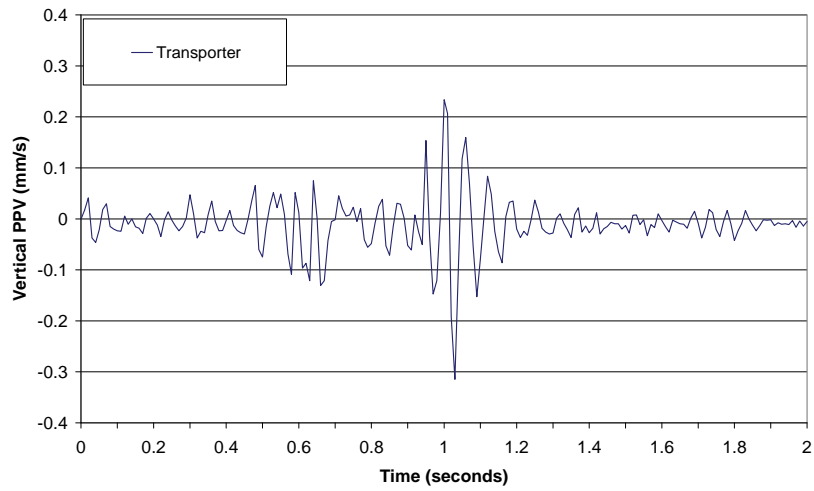
It can be seen that maximum levels are approaching twice that for two axle trucks (see Table 3.6). Three of the vehicles in the list were transporters carrying other vehicles. Interestingly, two of these transporters were included in the noisy vehicle list too.

Figure 3.16 gives the time histories of the three vehicles which produced the highest vibration levels. It can be seen that the highest vibrations occurred towards the end of the event i.e. when the trailer wheels passed over the irregularity. Because there were 3 axles in close proximity the vibration produced is a superposition of the vibration produced by each individual axle. This leads to a higher recorded frequency. In the case of the transporter producing the highest vibration levels the recorded frequency was estimated to be 17 Hz. This can be compared with 9-12 Hz from individual axles (see Section 3.3.1).

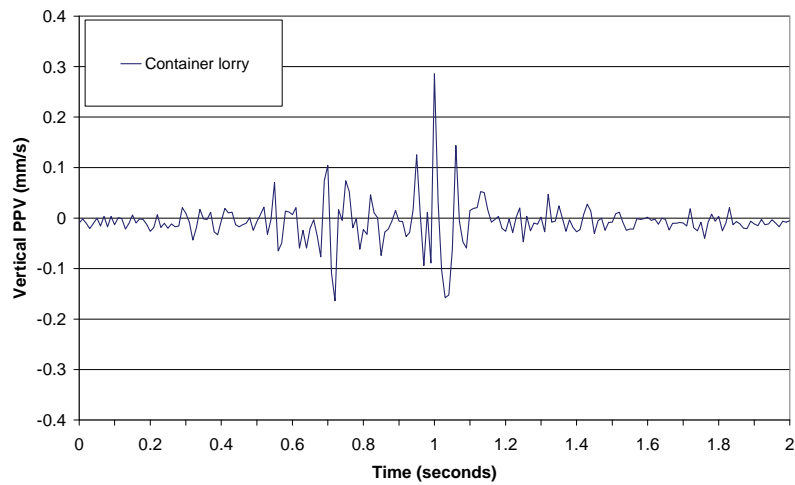
Table 3.7: Category 3 vehicles (heavy vehicles) producing highest vibration levels

Description	Age	Max PPV
Transporter full of SUVs also a "noisy vehicle" (5 axle, 11.7 litre)	<1 yr	0.32
Container lorry (5 axle)	N/K	0.29
Heavy vehicle transporter carrying 2 tractors also a "noisy vehicle"(6 axle, 11.7 litre)	4 yr	0.27
Artic carrying large unidentified object (6 axle, 11.7 litre)	4 yr	0.27
Artic with very large container with flapping sides (5 axle, 10.5 litre)	1 yr	0.27
Artic with canvas covered load (5 axle, 11.9 litre)	3 yr	0.26
Artic with trailer with canvas sides (4 axle, 12 litre)	3 yr	0.26
Artic with flatbed trailer and crane mounted behind cab (6 axle, 12.1 litre)	8 yr	0.25
Artic with curtain sided trailer (5 axle, 11.7 litre)	2 yr	0.24
Artic carrying large tractor (6 axle, 15.6 litre)	1 yr	0.24
Artic with curtain sided trailer (6 axle, 12.1 litre)	5 yr	0.24

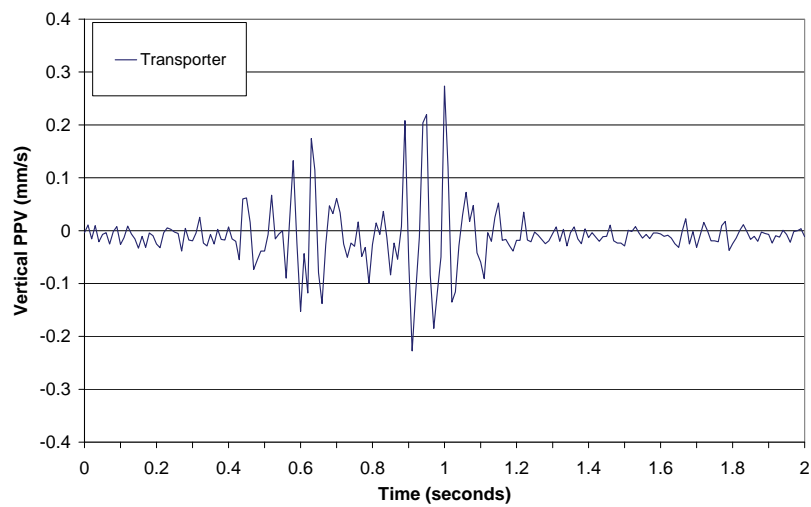
(a) Transporter



(b) Container lorry



(c) Transporter

**Figure 3.16: Time histories of vertical particle velocity (mm/s)**

4 Discussion of results

The results from the measurements of noise and vibration are discussed below.

4.1 Noise

The analysis was based mainly on the third octave analysis of pass-by noise together with the associated images. Body rattle noises were considered to cause the significant elevation of levels at 800Hz and above and exhaust noise around the fundamental firing frequency of the engine (typically in the 63 to 125 Hz range). Recent work has shown that where body rattle noise is heard from passing vehicles the frequencies in a broad band above 800 Hz are significantly elevated above similar vehicles with no identifiable noise source (Ainge et al., 2006). For discernable exhaust noise the frequencies are much lower. Figure 4.1 illustrates these points by providing the spectra¹ of a sample of heavy goods vehicles that were measured in London with different perceived noise sources. The sample size and average speed are given in brackets in the legend.

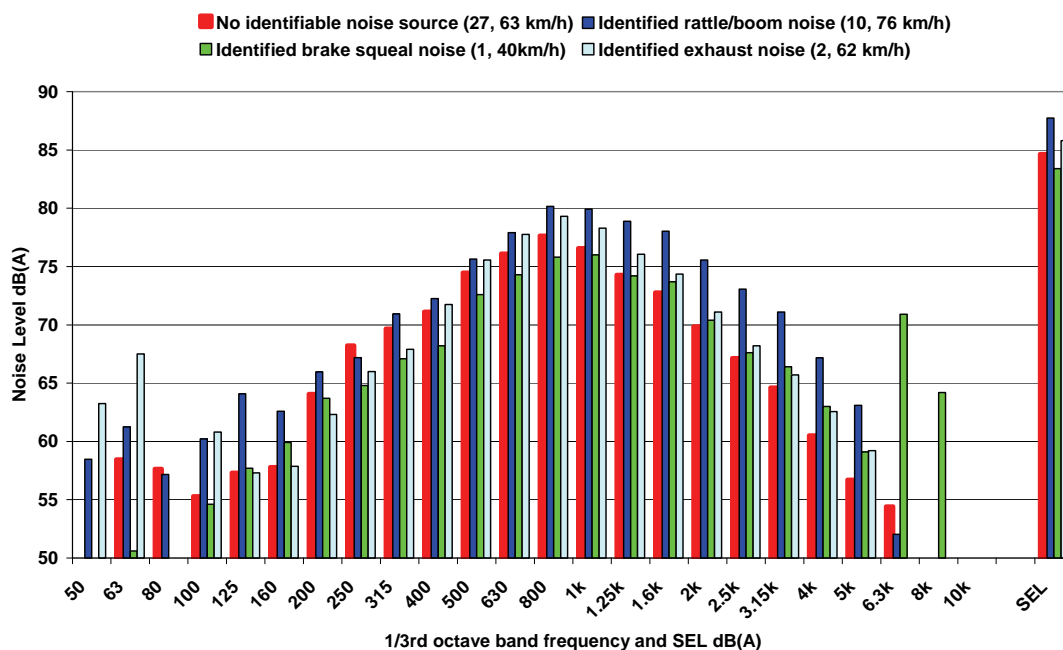


Figure 4.1: Spectra of vehicles identified as having various noise characteristics

In the present study it is clear from the relatively small sample of light vehicles that the age of the vehicle is a factor and whether a trailer was being towed. It was thought from the appearance and load carried that the trailer and contents were responsible for body rattle noises even on the relatively smooth surface (Site 1). Low frequency noise from vehicle exhausts was also thought to be a factor in two cases.

¹ Levels are given in terms of SEL dB(A) or sound exposure levels. This is the level of an event lasting for 1 second which contains the same acoustic energy as the entire event. At a given speed the maximum level is directly related to the SEL levels.

In the case of medium heavy vehicles it appeared body rattle noises were prominent and flapping covers in one case. Small vehicle transporters were identified as noisy at the second site with an uneven surface.

In the case of the heaviest vehicles sample sizes were larger so results are more robust. It was found that vehicle transporters made up the majority of noisy vehicles at the first site with the even road surface (6 out of 7). At the site with an uneven surface they represented 5 out of the 12 noisiest vehicles. In all cases the spectra revealed excessive levels at mid to high frequencies indicating rattle noise.

Inspection of the images reveals some of the reasons for the rattle noises on transporters. The reasons can be grouped as follows:

- Loose chain safety fences along the sides of the bays
- Loose vehicle securing chains
- Loose vehicle ramps
- Loose components on hydraulic hoists
- Loose components on the vehicles being transported (e.g. construction site vehicles)

The code of practice for body rattle noise (DETR, 2000) provides guidance on methods of preventing such noise. It is likely that there are particular challenges in reducing rattle noises for this type of vehicle because there are many loose metal components and more detailed investigations of the major sources and their elimination are required.

A particular feature of the observed body rattle noises was the impulsive nature of the noise peaks. Such rapid increases in noise would be particularly annoying to residents living close to the road especially at night time where sleep disturbance is likely. The WHO sets guidelines on maximum levels outside bedroom windows at night to avoid health effects (WHO, 2001). Currently this is set at 60 dB(A). They state: "Even if the total equivalent noise level is fairly low, a small number of noisy events with a high maximum sound pressure level will affect sleep". It can be seen in Figure 3.11 that the maximum level produced at 7.5m from a fully laden car transporter was 96 dB(A) which is a very high level indeed and 8 dB(A) above the average level at this site. If we assume that the sound level decays at a rate of 6 dB(A) per doubling of distance² and that ideal and unobstructed propagation conditions exist then the threshold value 60 dB(A) level could be exceeded at several hundred metres from the road. Hence the number of people that could potentially be affected by such a vehicle could be very large.

In some cases the heavy vehicles were obviously relatively old and worn and there was evidence of excessive exhaust / engine noise. Over the last two decades vehicle noise limits at type approval have fallen by over 10 dB(A) so modern diesel engines are likely to be considerably quieter than older examples. In addition a worn engine / exhaust is likely to produce more noise than a new system especially if the vehicle has been poorly maintained.

In a further stage of the project the details of a random sample of vehicles passing the measurement point will be examined from the video records in order to determine the percentage of transporters and older vehicles in the general vehicle fleet. In this way it will be possible to quantify the full extent to which these categories of vehicles are over represented in the noisy vehicle category.

² Over hard ground the attenuation rate of a compact source is 6dB(A) per doubling of distance. It is assumed that the major rattle noise can be approximated by a point source

4.2 Vibration

It is difficult to put the absolute recorded levels of vibration into context though we can make some estimates based on predictions on a stiff clay soil consistent with the shallow lime rich soils overlying chalk in the area of Site 2. Watts has developed an equation that estimates the peak particle velocity (PPV) expected alongside a road with a significant surface defect (Watts, 1990). The prediction equation for peak particle velocity (PPV) in mm/s is given by:

$$PPV = 0.028a \frac{v}{48} tp \left(\frac{r}{6} \right)^x$$

where:

a = maximum height or depth of the surface defect in mm which was assumed in this study to be 10mm

v = vehicle speed in km/h which was in this case assumed to be close to the maximum regulated speed for heavy trucks (90 km/h)

t = ground scaling factor which at site 2 was assumed to be similar to a stiff clay (i.e. 0.43)

p = 1 since the defect lies in both wheel tracks (if only in one wheel track $p = 0.75$)

r = distance from the irregularity in the nearest wheel track to the measurement point which in this case is 6 m

x = -0.93 which is the value of the distance attenuation constant which was assumed to be similar to a stiff clay

With these inputs the equation yields a maximum predicted level of 0.23 mm/s. In fact the maximum recorded level was 0.32 mm/s which is above the predicted level indicating that this recorded level is likely to be relatively high. The average vibration level at the site was approximately 0.16 mm/s i.e. half the level produced by the vehicle producing the maximum level. To provide context for these vibration levels a value of 0.3 m at building foundations may well be perceived by occupants on suspended wooden floors (Watts, 1990).

An examination of the time histories of the largest vibration events indicate the importance of the rear axle or trailer axle in producing the maximum vibration levels. Clearly the heavy class of vehicles (Category 3) produced higher levels than the medium heavy category (Category 2) by a factor of nearly 2. Two of the vehicles producing high vibration levels also produced relatively high levels of noise and appeared old. Some of the trailers that produced these relatively high vibration events were heavily laden. For example the transporter fully laden with large SUVs produced the highest level. The age of the vehicle may be a factor because suspension systems have changed over recent years. Today most trucks have air suspension while previously steel leaf spring systems were more common. The spring rate of heavily compressed steel springs will rise significantly as the “helpers” begin to contribute. Some leaf springs have an excessively high spring rate when unladen. However the change in spring rate with load is likely to be more linear in the case for air suspension and therefore inappropriate spring rates less likely. An excessively high spring rate for the load conditions will contribute to higher dynamic loads on the road pavement and hence a greater amplitude of vibration at the roadside (Watts et al, 1997).

The degree of damping will also affect the maximum force applied to the road. In the case of defective dampers the travel of the suspension may be excessive when the wheels travel over an irregularity. In such a case the suspension may reach its limits of travel and hit the bump stops producing extremely high dynamic forces and consequently vibration. Note that this can occur in both

air and steel suspension systems. An old or poorly maintained vehicle is more likely to have a defective suspension system than a new, well maintained vehicle.

In terms of remedial strategy it will be important to improve suspension maintenance and to phase out the use of steel spring suspensions where it can be shown that there will be tangible benefits.

5 Summary and conclusions

The study describes an efficient method for gathering information at the roadside on vehicles producing excessive noise and / or vibration. The analysis has shown that body rattle noise produced on both a relatively smooth and an uneven road surface is likely to be the cause of most excessive noise. Excessive exhaust noise is another relatively common cause. Aerodynamic noise was not thought to be widespread although an edge tone may have been detected in one instance. Air turbulence however can have an indirect on noise production by causing loose covers and securing straps to vibrate and flap causing noise across a wide range of frequencies.

The age of the vehicles appears to be an important factor in some cases, probably due to worn engine / exhaust systems that are likely to emit more noise than newer ones.

Vehicle transporters were frequently identified as relatively noisy and an examination of the spectra indicates the importance of body rattle noise. The recorded images suggest a number of possible sources on the trailer but further work is recommended before definite conclusions are reached.

The highest levels of vibration were recorded for the heaviest category of truck as expected. The rear axles produced the highest vibration levels and heavily laden older vehicles were found to produce relatively high vibrations levels. The type of suspension may be a factor too: newer suspensions types incorporate air springs while older vehicles are fitted with steel leaf springs. The latter are more likely to produce higher dynamic loading on the road pavement when unladen and hence generate more vibration. However, both systems have the potential to produce high dynamic loads and hence vibration if shock absorbers are defective.

By establishing the causes of excessive noise and vibration and tackling the relatively small number of vehicles that are a problem could provide a relatively low cost way of reducing disturbance. For example it is known that limiting maximum noise levels are particularly important in controlling sleep disturbance. This may provide a powerful addition to the control measures traditionally used to combat noise disturbance which tend to reduce the average noise levels but fail to reduce the range of noise levels (e.g. by noise barriers and low noise road surfaces).

It is proposed that in a further phase of the project the noise from light vehicles will be examined on a road with a smaller lorry flow than the A34. It was found that because of the high percentage of trucks in the traffic flow it was not possible to obtain a sufficient sample of light vehicles which were uncontaminated by the noise from trucks on the opposite carriageway.

It is also proposed to measure the vibration produced on a lower speed road. This will cover the case of vehicles going over a large irregularity or traffic calming device where a significant vertical deflection is involved. On high speed roads such as the A34 it is difficult to find significant irregularities due to the need to maintain a safe road surface.

The results will be useful in developing policy on noisy vehicles and will be of use to manufacturers aiming to provide low noise vehicles and trailers for use in noise sensitive areas e.g. where the local authority has placed restrictions on noisy vehicles operating on parts of the road network at night.

Acknowledgements

The work described in this report was carried out in the Noise and Vibration Research Team of TRL Limited. The authors would like to thank Geoff Helliwell and Rob Beaumont who assisted with the survey work, and Tristan Brightman for assistance with the analysis. The authors are grateful to Dr Paul Nelson who carried out the technical review of this report.

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Characteristics of vehicles producing excessive noise and ground-borne vibration – Phase 1



It is recognised that it is almost always the average noise level on roads and highways that is the subject of attention because it has been directly linked to noise annoyance caused to residents. However, an alternative approach in examining nuisance is to consider the noise caused by the noisiest vehicles or those producing the highest vibration levels. Noisy vehicles can have a very wide footprint and can cause widespread disturbance. Reducing maximum levels of noise in residential areas is likely to reduce sleep disturbance which is a major factor affecting overall annoyance.

A programme of research was commissioned by the Transport Research Foundation, as part of the self-funded research programme, to address how to identify excessively noisy vehicles and examine the characteristics of such vehicles when they are in use.

The first phase of the programme, described in this report, involved the development of the basic test methodology and initial trials at the roadside, with the main focus on identifying the sources of excess noise on heavy goods vehicles.

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