Quantification of Noise and Vibration Effects Arising from Higher Mass Limits for Heavy Vehicles

OPUS

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Prepared By

Tim Divett
Research Scientist

Peter Cenek
Work Group Manager
Physical & Engineering Sciences

Opus International Consultants Limited
Central Laboratories
138 Hutt Park Road, Gracefield
PO Box 30 845, Lower Hutt 5040,
New Zealand

Reviewed By

Vince Dravitzki
Work Group Manager
Transport and Environmental Sciences

Telephone: +64 4 587 0600
Facsimile: +64 4 587 0604

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Executive Summary

The Ministry of Transport engaged Opus International Consultants Ltd to carry out a study to determine if there were any significant differences in noise and vibration levels between a truck loaded to a total weight of 44 tonnes and the same truck loaded to a total weight of 49 tonnes. As part of the Heavy Vehicle Productivity Project, a trial to assess the impact of increasing the loading of trucks was already being undertaken by the Ministry of Transport in conjunction with the movement of municipal waste from Christchurch to the Kate Valley Landfill by Canterbury Waste Services. As a consequence, the noise and vibration levels of each type of truck were able to be measured as each truck passed a measurement position located near the road edge.

The noise and vibration from the Canterbury Waste Services trucks carrying one of the two loadings were measured at five different sites in or near to Christchurch. The sites selected represented a number of situations that would be typically encountered by heavy vehicles and which might cause more noise or vibration if the vehicle was heavier.

These sites included:

- An intersection where vehicles need to accelerate back up to speed.
- A road section with a gradient.
- A normal urban road sealed with a smooth asphaltic concrete surface.
- A high quality highway sealed with a quiet road surface.
- A highway section displaying moderate to high deflections surfaced with chipseal.

Previous traffic noise studies in New Zealand have established that a sample size of at least five and preferably ten passing trucks would be required to reliably detect any differences brought about by wheel loading. This sample size condition was satisfied for the majority of the sites monitored as part of the noise and vibration measurement programme so there can be a degree of confidence that the resulting programme findings are valid. Furthermore, the noise and vibration effects were consistent with expectations across the five sites.

The principal finding was that although there was some difference in the mean values between the two loaded truck configurations at all the sites where noise and vibration monitoring took place, the 95 percent confidence intervals overlapped. Therefore, it can be concluded that increasing vehicle weight by 11% from 44 tonnes to 49 tonnes has no significant effect on noise and vibration levels.

A second finding was that road and site conditions have considerably more of an effect on traffic induced noise and vibration levels than the wheel loading of heavy commercial vehicles.

CLIENT: Ministry of Transport
P.O. Box 3175
Wellington 6140

CONTACT: Nicola White
Project Administrator
Land Transport Investment & Development

1 Introduction

1.1 Report Outline

Section 1 of this report describes the scope of the work undertaken, impacts of other activities on the measurement programme, expected effects of increased vehicle loading on noise and vibrations and background to the measurement units of noise and vibration. Section 2 details the procedures used in monitoring noise and vibrations generated by Canterbury Waste Services vehicle travelling to and from the Kate Valley landfill. Section 3 provides results of the monitoring programme in the form of graphical comparisons of unloaded, 44 tonne and 49 tonne vehicle configurations at each of the 5 sites monitored. A discussion of how the measured results agree with expectations is provided in Section 4. Conclusions from this report are summarised in Section 5. References and appendices covering site details, result summaries and license plates of the monitored vehicles follow.

1.2 Scope of Work

Following from Transit New Zealand's research into higher mass and dimension limits for heavy vehicles, the Ministry of Transport has conducted a six month trial to better quantify economic, safety and environmental effects that result from allowing heavier trucks, and possibly longer trucks, to operate on selected routes.

This report is associated with establishing the differences in noise and vibration when the allowable mass of a truck and trailer unit is increased from 44 tonnes to 49 tonnes, but with the truck and trailer unit being the same for the two different loadings, thus the change being in the loading not the vehicle.

The measurement of the change in noise and vibration was undertaken in conjunction with one of the trials being undertaken by the Ministry of Transport that involved Canterbury Waste Services vehicles transferring waste from Christchurch to a distant landfill.

The route selected is that used by Canterbury Waste Services to cart processed waste from the Parkhouse and Styx Mill Transfer Stations located in the Christchurch suburbs of Wigram and Redwood, respectively, to the Kate Valley Landfill some 70 km to the north-east of Christchurch. The landfill is sited within coastal hill country approximately 10 km to the north-east of Amberley off Mt Cass Road, Waipara. Therefore, the route covers urban and rural speed environments and comprises largely State Highway (SH) 1. The route passes through several rural settlements including Belfast, Kaiapoi, Woodend and Amberley.

Twelve identical Mercedes truck and trailer units were involved in the trial, seven having a maximum weight of 49 tonnes and five having a maximum weight of 44 tonnes, which is the current maximum allowable weight. These vehicles had been expected to make a total of about fifty trips to the landfill a day during the course of a 16 hour period. Therefore there would be numerous opportunities to perform comparative noise and vibration measurements under close to identical environmental conditions so that the effect of increased mass could be accurately quantified.

The noise and vibration measurements to be made were of each vehicle as it passed by a measurement site located several metres from the road edge on its way to and from the landfill, so that both loaded and unloaded configurations of each vehicle could be monitored.

1.3 Impact of Traffic Management Requirements on Measurement Programme

As the noise and vibration monitoring took place adjacent to state highways, traffic management was required. In previous work in other projects, this was a minimal imposition but for the sites of this study, the network manager required full shoulder closure coupled with a time restriction when closure could occur. This limited the time monitoring could take place to between 9am and 5pm. With approximately two hours taken up with setting up and removing the monitoring equipment at each site, the requirement for traffic management imposed severe restrictions on the time available for monitoring the Canterbury Waste Services truck and trailer units. A further restriction was the scheduled closure of the landfill on Wednesday afternoons. As a consequence, the number of trucks that were able to be monitored at a site was significantly lower than expected.

1.4 Expected Noise and Vibration Effects

The environmental evaluation undertaken as part of Transit New Zealand's research study "Improving Heavy Vehicle Efficiency," (refer http://www.transit.govt.nz/news/heavy-vehicle.jsp), identified that any changes in noise occurring from an increase in vehicle mass would be predominantly tyre/road noise but there could be some situations where engine noise was both increased and the dominant noise source.

Increasing the vehicle load without altering the vehicle results in increased tyre/road interface noise mechanisms. These mechanisms are caused by passages and grooves in the tyre compressing and distorting (Sandberg and Ejsmont, 2002). Generally noise will increase by 3 dBA if the load on each tyre is doubled. Some specific noise sources, such as tyre whine, may also increase. For truck tyres, high frequency whine is normally generated on stiff, smooth textured bituminous surfaces at higher speeds.

Situations where increased vehicle mass is likely to result in increased noise generation because of higher power demand include pavements that display high deflections under wheel loading as power is required to climb out of the depression that forms, acceleration from intersections and roundabouts or on exiting curves, and climbing gradients.

Ground vibrations induced by heavy traffic have been shown to be a function of speed, vehicle weight, and road roughness (Rudder, 1978). The expected change in ground vibrations at the road verge arising from an 11% increase in vehicle weight from 44 tonnes to 49 tonnes is calculated to be in the vicinity of 5 to 6% using the traffic vibration prediction model developed for the US Federal Highway Administration (Rudder, 1978) and assuming homogenous road surface roughness. By comparison, an increase in speed from 50 km/h to 60 km/h is expected to increase traffic induced ground vibrations by about 17%, all conditions being equal.

1.5 Equivalent Noise Level

The equivalent noise level is the time-averaged sound level over the measurement period, 100 milliseconds (ms), that has the same mean square sound pressure level as the time-varying sound level under consideration. Equivalent noise level is commonly referred to as an 'energy average' measure of sound exposure. In this study, the measurement period was 100 ms, which corresponds to approximately 2.5 metres of travel by the vehicle when travelling at 90 km/h.

Noise is measured in dBA, which means that an A-weighting has been applied to the spectral content of the sound pressure to reflect the response of the human ear.

With regard to the population's ability to detect noise, the human ear is not particularly sensitive to loudness but is very sensitive to tone. Literature often quotes a 3 dBA change as being at the limits of perception. However, in Land Transport Research Report 292 (Dravitzki and Kvatch, 2007), there was reliable measure of changes in population response to changes in road traffic noise when the change in noise was only 1 to 2 dBA.

1.6 Ground Vibration Units

Standards used for evaluating the effect of vibrations in terms on humans (e.g. NZ/ISO Standard 2631-2, 1989) and buildings (e.g. DIN 4150-3, 1999) are formulated around root-mean-square (rms) accelerations and/or peak velocities. Therefore, the following transformations are employed:

$$\text{rms accl}^{n}\ (\text{m/s}^2) = \frac{\text{peak accl}^{n}\ (\text{m/s}^2)}{\sqrt{2}} \quad \ldots (1.1)$$

and

$$\text{peak vel.}\ (\text{mm/s}) = \frac{1000 \times \text{peak accl}^{n}\ (\text{m/s}^2)}{(2 \times \pi \times f)} \quad \text{where f = axle bounce frequency (Hz)} \ldots (1.2)$$

The typical axle bounce frequency for heavy commercial vehicles ranges between 8 -15 Hz for "walking beam" suspensions and 10 - 15 Hz for air suspensions. Typically, an axle bounce frequency of 10 Hz is assumed as this corresponds to the lowest frequency that covers both suspension types. With reference to Equation 1.2 above, a low bounce frequency will give "worst case" (i.e. conservative) estimates of peak velocities.

In this report, the measured traffic induced ground vibrations are provided in terms of peak accelerations, since this is a direct measurement.

2 Measurements

2.1 Selection of Test Sites

Noise and vibration was measured at five sites adjacent the route to the landfill. The five sites were chosen to cover the following situations considered most likely to exaggerate differences in noise and vibration levels brought about by additional wheel loading.

1. acceleration when at about 30 km/h (noise only)
2. constant uphill gradient (noise only)
3. smooth asphaltic concrete surfaced road in urban (50 km/h) setting (noise and vibration)
4. smooth open graded porous asphalt (OGPA) surfaced road in rural (90 km/h) setting (noise and vibration)
5. rough, flexible chipseal surfaced road in rural (90 km/h) setting (noise and vibration)

Specific details of the sites selected are provided in Appendix A.

2.2 Instrumentation Set - Up

The intention was to measure noise and vibration on both sides of the road, to capture loaded trucks travelling to the landfill and unloaded trucks travelling back to Christchurch from the landfill.

A video camera and an infra-red traffic logger (TiRTL™) were used to capture the traffic movement to later assist with identification and timing of vehicles, so that the logged noise and vibration data could be matched to specific vehicles.

A radar gun was used to measure the speed of each Canterbury Waste Services vehicle. Any of those vehicles travelling unusually fast or slow were excluded from the results.

At each of the five sites, a Rion NL-32 sound meter was placed 1.5 metres above the road surface, 3 metres from the kerbside wheel path of the landfill-bound vehicles, to measure the noise of passing fully laden trucks.

At sites 2, 3 and 4, a Rion NL-31 sound meter was placed 1.5 metres above the road surface, 3 metres from the kerbside wheel path of the returning trucks, to measure the noise of the unloaded Canterbury Waste Services trucks to check that there was no significant difference in the noise level between the unloaded trucks. At site 3, this sound level meter was also used to measure the noise of the laden landfill-bound trucks, due to the failure of the other noise meter that had been set up on the landfill-bound side of the road. Some measurements at site 3 were unable to be used because there was a vehicle passing in the near Christchurch-bound lane at the same time as a laden Canterbury Waste Services truck was passing in the landfill-bound lane. The noise levels of the more distant laden trucks were less than if measured close by. In the data presented, this lower recorded noise level for the landfill-bound direction at site 3 has been adjusted by +7 dBA to allow for the greater distance to the measurement location.

The availability of only one working sound level meter adjacent to the Christchurch-bound lane at site 3 was not ideal, but still allowed any differences between Canterbury Waste Services vehicles travelling on the same side of the road to be readily identified.

The sound measuring equipment is calibrated to primary acoustic standards and measurement methods were in accord with the general measurement standard NZS 6801:1999.

At sites 3, 4 and 5, four Colibrys Si-Flex™ tri-axial accelerometers were set up to measure ground borne vibrations. On each side of the road, one accelerometer was set up 2 metres from the edge line marking on the road surface and the second accelerometer was mounted on metal spikes driven into the earth 6.5 metres from the edge line marking. Only acceleration data measured by the accelerometers 2 metres from the lane edge marker were used in the analysis. These accelerometers were used to measure the vibration at 1000 Hz using a Measurement Computing PMD 1608FS data acquisition card connected to a laptop running LABVIEW™ data acquisition software. The accelerometers and data logging instrumentation employed are traceable to primary standards to ensure the integrity of the vibration measurements.

The measurements were taken between 10:30am and 3:30pm on the 6th, 7th, 20th, 9th, and 10th October 2008 at sites 1 to 5 respectively.

Photographic views of the instrumentation setup are given in Figures 1, 2 and 3.

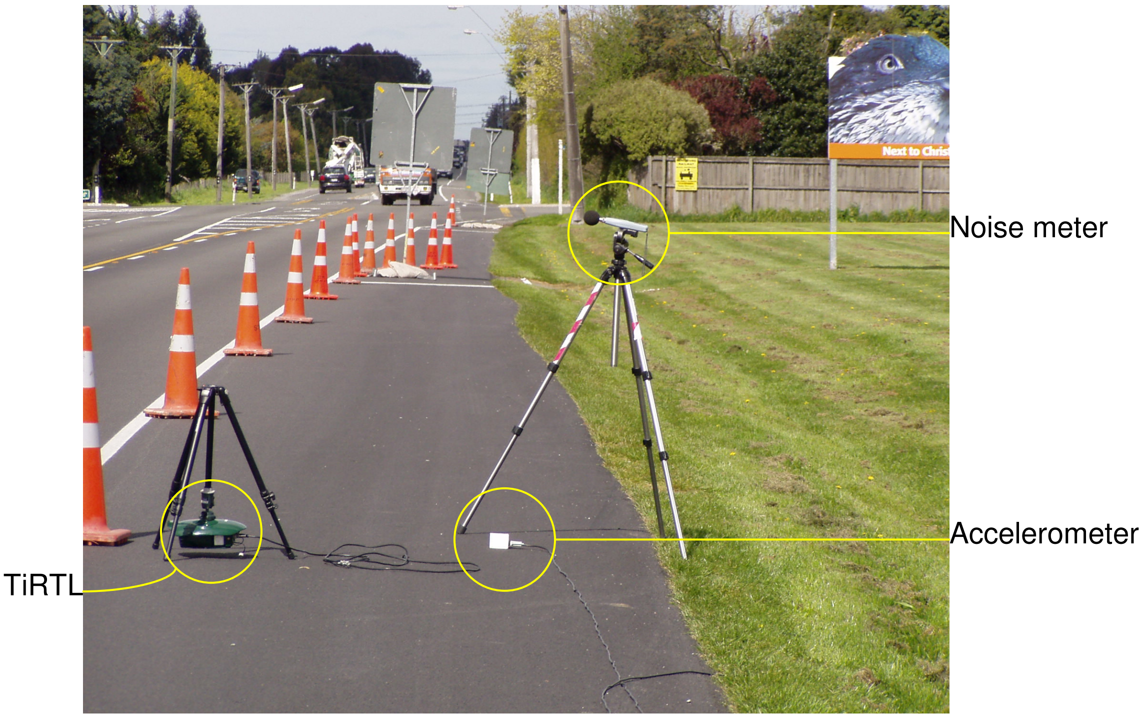

Figure 1: The TiRTL (lower tripod), noise meter (tall tripod) and accelerometer (little white box on road) installed at site 4, Christchurch - bound side of the road.

Figure 2: Noise meter (tall tripod) and accelerometer (little white box on ground) as installed at site 3, landfill – bound side of the road

Figure 3: The radar gun and video camera in use at site 5

2.3 Data Recording

The sound level meters were set to record $L_{eq,100ms}$ continuously. The sound data was time stamped and by using this time stamp and the video record, the noise of each passing truck could be identified. Within this data cluster, the maximum $L_{eq,100ms}$ value for each passing Canterbury Waste Services truck was selected to represent the loudest sound level for that passing truck. This maximum sound level reading corresponds to 1.5 to 3.0 metres of travel while the truck is directly opposite the measurement site.

Similarly, the maximum instantaneous vertical acceleration was recorded for each passing Canterbury Waste Services truck.

For each site, a statistical analysis was performed on the acquired sound level and vibration measurements to yield mean values and associated 95% confidence intervals. These statistics along with the corresponding mean vehicle speed are reported in Appendix B.

2.4 Vehicle Identification

The actual laden weight of the Canterbury Waste Services trucks participating in the Ministry of Transport higher mass trial ranged between 47.5 and 49 tonnes for those operating at the higher 49 tonne mass and between 44 and 44.5 tonnes for those operating at the reference 44 tonne mass (Rutledge, 2008). Therefore, the license plate of each passing Canterbury Waste Services truck was recorded at the time of passing the site. The license plate was then compared with a table of license plates of the Canterbury Waste Services trucks involved in the higher mass truck trial to ascertain the nominal loaded weight of that truck. This table of license plates is given in Appendix C.

3 Results

3.1 Ground Borne Vibrations

Figure 4 shows the maximum instantaneous vertical accelerations, averaged over the number of Canterbury Waste Services trucks passing, together with the 95 percent confidence intervals.

Although there is some difference in the mean values between the two loaded truck configurations at all three sites where vibration monitoring took place, the 95 percent confidence intervals overlap so it can be concluded that the ground vibration levels induced by the 49 tonne trucks are comparable to those induced by the 44 tonne trucks.

Another feature to note in Figure 4 is that ground vibrations induced by unloaded Canterbury Waste Services trucks are of comparable magnitude to the loaded truck configurations.

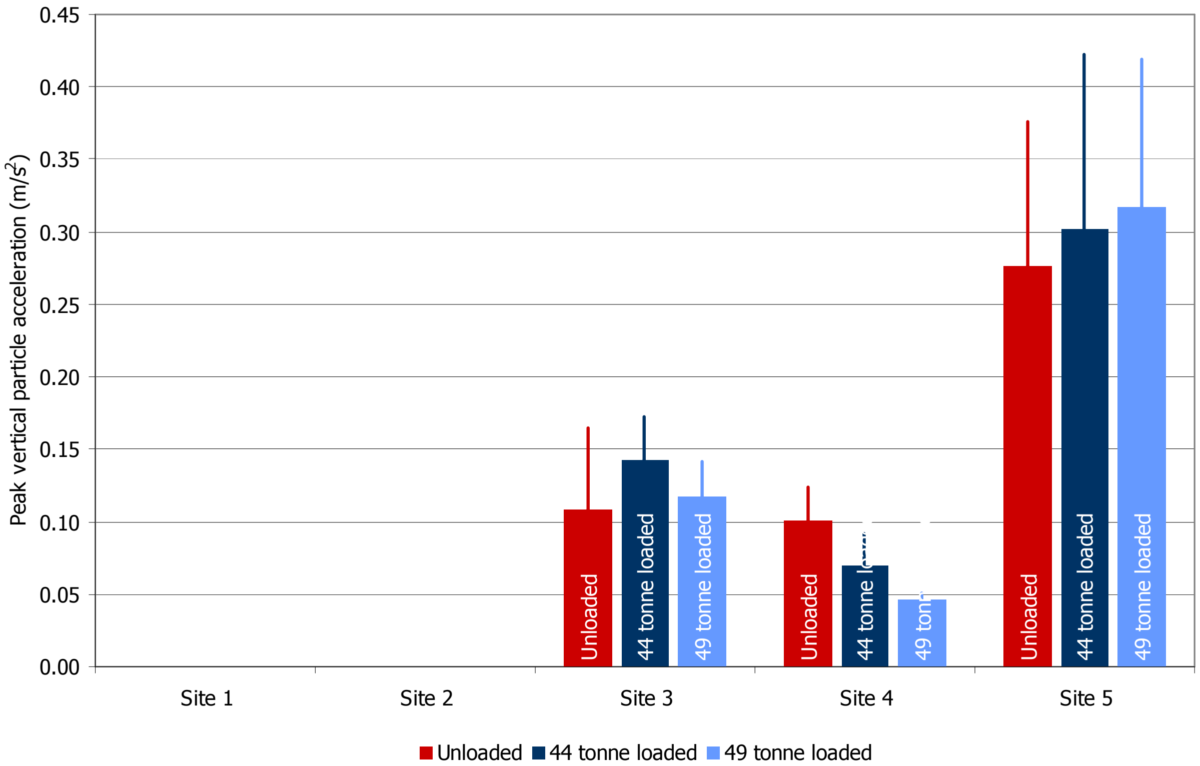

Figure 4: Comparison of ground vibrations 2 m from the lane edge marker. (The heights of the bars are mean values and error bars are the 95% confidence intervals.)

3.2 Drive-by Noise

Figure 4 shows the $L_{eq,100ms}$ measured at a distance of 2 metres from the kerb-side wheel path, averaged over the number of trucks passing, together with the 95 percent confidence intervals.

With reference to Figure 5, no significant difference between the drive-by noise generated by the 44 tonne trucks and those induced by the 49 tonne trucks has been measured at any of the 5 sites where noise monitoring took place. Although there is some difference in the mean noise levels between the two loaded truck configurations at site 5, the 95 percent confidence intervals overlap so it can be concluded that at site 5 drive-by noise levels generated by the 49 tonne trucks are comparable to those generated by the 44 tonne trucks.

Figure 5 also shows that when unloaded, the Canterbury Waste Services trucks monitored generate drive-by noise levels that are of comparable magnitude to the two loaded truck configurations. Therefore, as for vibrations, it appears that road and site conditions have more of an influence on drive-by noise levels than wheel loading.

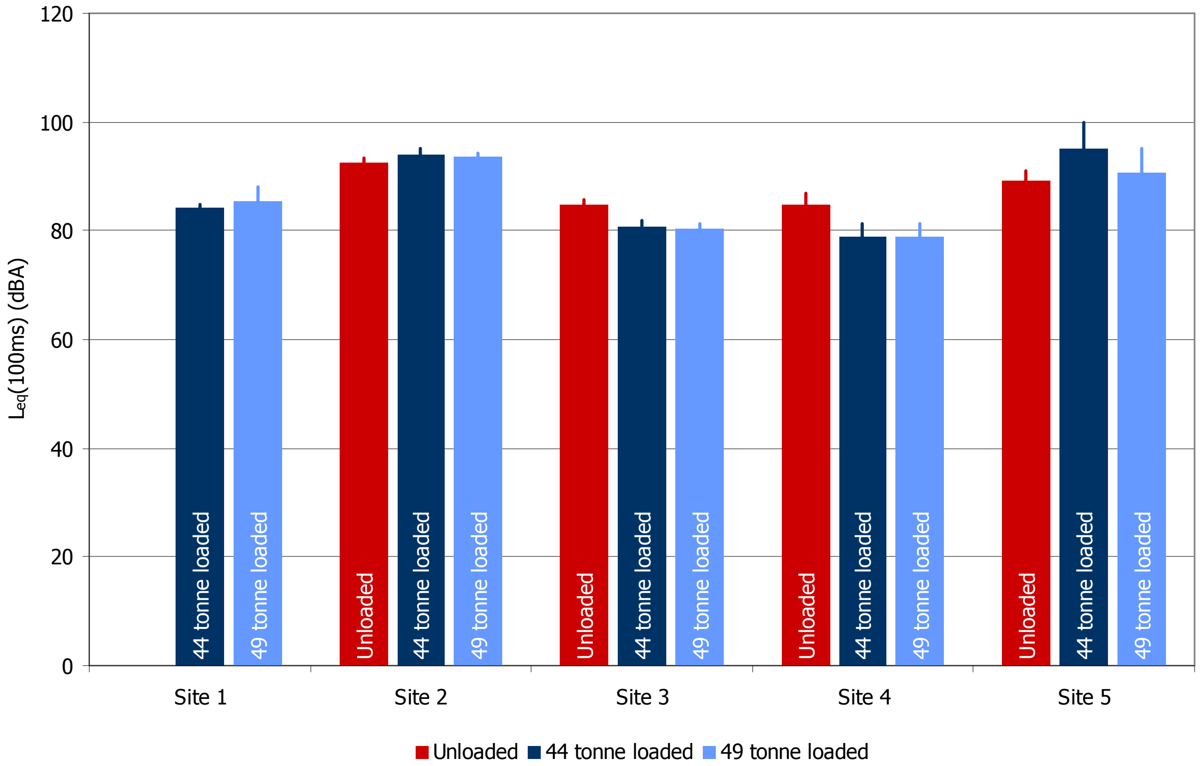

Figure 5: Comparison of drive-by noise levels 2 m from the kerb-side wheel path. (The heights of the bars are mean values and error bars are the 95% confidence intervals.)

4 Discussion

The results presented in section 3 show that the noise and ground vibrations induced by the individual trucks are quite variable, but within this variability the trend for differences in noise and vibration between trucks at 44 tonnes and trucks at 49 tonnes, although small, is clearly evident. In some instances, the noise and/or vibration of the heavier (49 tonne) vehicles is less than the effects from the lighter (44 tonne) vehicles and both types of loaded vehicles show less noise or vibration than the unloaded vehicle. This is not unusual in that unloaded trucks can be more prone to the effects of rough patches on the road and some suspensions perform better when loaded.

Despite the comparatively small sample numbers at each of the 5 sites monitored, we can have a degree of confidence that the findings are valid. The reasons for making this statement are twofold.

Firstly, the trends in the mean site noise and vibration levels are as expected in that:

- For a comparable level of surface roughness, traffic vibration levels are considerably higher on the section of state highway that deflects more under wheel loading (site 5) than the sections of highway with low deflection (sites 3 & 4)
- Noise levels measured on the noise reducing open grade porous asphalt (OGPA) site (site 4) for a traffic speed of 90 km/h are comparable to the noise level measured on a smooth asphaltic concrete surface for a traffic speed of 50 km/h.
  N.B. The 40 km/h increase in speed is offset by the noise reducing properties of the OGPA surface.
- Noise levels measured at the two chipseal sites displaying comparable surface texture and surface roughness (sites 2 and 5) are almost identical.
- Noise levels recorded at site 1 as the Canterbury Waste Services trucks are accelerating to 50 km/h are comparable to the noise level at site 3 when the trucks are travelling at a constant 50 km/h.
- The highest noise levels for the trucks in the loaded configuration were consistently measured at site 2, which was located on a moderate (3% - 5%) incline.

Secondly, the method used by Central Laboratories to measure noise is an adaptation of the International Standard, ISO 11819-1:1997, titled "Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 1: Statistical pass-by method".

In ISO 11819-1:1997, the noise of each passing vehicle is measured and a sample of about 100 vehicles is used to determine the average. Central Laboratories has successfully used a modified method for noise measurement using a smaller sample size (Dravitzki et al, 2006).

Using a single test vehicle and with careful driving control so as to uniformly pass the measurement point, the standard deviation of about five runs is 0.5 dBA for a car or truck-trailer unit. Furthermore, the mean is stable, in that additional runs do not change it by more than 0.5

dBA. Measuring a sample of about ten passing vehicles selected from normal road traffic, either cars or truck-trailer units but averaged separately, the standard deviation is about 2.2 dBA and the mean is stable in that adding more vehicles to the sample changes the mean by less than 1 dBA. Using this method we were able to identify differences in road surface effects ranging from about 1 dBA to 6 dBA, dependent on type.

For this monitoring programme considering the effect of wheel loading, the method employed for measuring drive-by noise is essentially the same. The small differences in noise expected should be encompassed by the experimental variation but if the noise difference between loaded and unloaded trucks was significant it could be reliably detected, so long as the sample size was sufficient with at least five and preferably ten passing trucks being necessary to establish each data point reliably.

With reference to Appendix B, the minimum number of 5 passing trucks has been exceeded in the majority of cases.

5 Conclusions

Within the scope and limitations of the field study undertaken, there should be no noticeable noise and vibration effects by increasing vehicle weight by 11% from 44 tonnes to 49 tonnes. This result confirms expectations from the desktop based environmental evaluation undertaken as part of Transit New Zealand's research study "Improving Heavy Vehicle Efficiency," (refer http://www.transit.govt.nz/news/heavy-vehicle.jsp).

A second, important result, was that road and site conditions have considerably more of an influence on traffic induced noise and vibration levels than the wheel loading of heavy commercial vehicles.

6 References

DIN 4150-3 *Structural Vibration Part 3: Effects of Vibration on Structures* (1999) Deutches Institut für Normung, Berlin, Germany, 1999.

Dravitzki, V., Walton, D., and Wood, C. (2006) *Road Traffic Noise - Determining the Influence of New Zealand Road Surfaces on Noise Levels and Community Annoyance*. Land Transport New Zealand Research Report 292. 76 pp.

Dravitzki, V., Kvatch, I. (2007) *Road Surface Effects on Traffic Noise: Stage 3 - Selected Bituminous Mixes.* Land Transport New Zealand Research Report 326. 40 pp.

International Standard ISO 2631-2:1989(E) *Evaluation of Human Exposure to Whole-Body Vibration- Part 2: Continuous and Shock-Induced Vibration in Buildings (1 to 80 Hz).*International Organization for Standardization, Geneva,1989.

International Standard ISO 11819-1:1997 *Acoustics - Method for measuring the influence of road surfaces on traffic noise - Part1: The Statistical Pass-by Method.* International Organization for Standardization, Geneva, 1997.

Rudder,F.F. (1978) *Engineering Guidelines for the Analysis of Traffic-Induced Vibration.* Report No FHWA-RD-78-166, US Department of Transportation, Washington, D.C.

Rutledge, H. (2008) Personal Communications with Harry Rutledge, Transportation Manager at Canterbury Waste Services.

Sandberg, U. and Ejsmont, J.A. (2002) *Tyre/Road Noise Reference Book*, Informex, Sweden.

Appendix A: Site details

The New Zealand Transport Agency's RAMM state highway database was interrogated to identify candidate sites suitable for measuring noise and vibration characteristics from Canterbury Waste Services truck and trailer rigs travelling between The Parkhouse and Styx Mill transfer stations and the Kate Valley landfill located approximately 70 km north-east of Christchurch off Mt Cass Road.

Data from surfacing and roughness tables in RAMM was used to select sites with particular surfacing requirements whereas data from the falling weight deflectometer (FWD) table in RAMM was used to select sites where large pavement deflections were likely to occur.

For each site monitored, a description of the site, road reference locations for the start and end points, and map plots from Google - Map are provided to assist in locating the selected sites. Five sites in total were utilised. A particular feature of all sites is the presence of a sufficient open area for setting up the monitoring equipment and to act as a safety zone for personnel.

The particular features of each site monitored are summarised below.

A1 Site 1: Acceleration when at about 30km/h (noise measurements only)

Site 1 was located at the exit from Styx Mill Transfer Station, Styx Mill Road. The road section of interest is from the entrance of Styx Mill Transfer Station to the intersection of Styx Mill Road with Main Road North i.e. SH74.

Only noise measurements for loaded trucks leaving the Transfer Station was possible so the instrument set up was limited to north-bound side of Styx Mill Road - see aerial view of Styx Mill Road below.

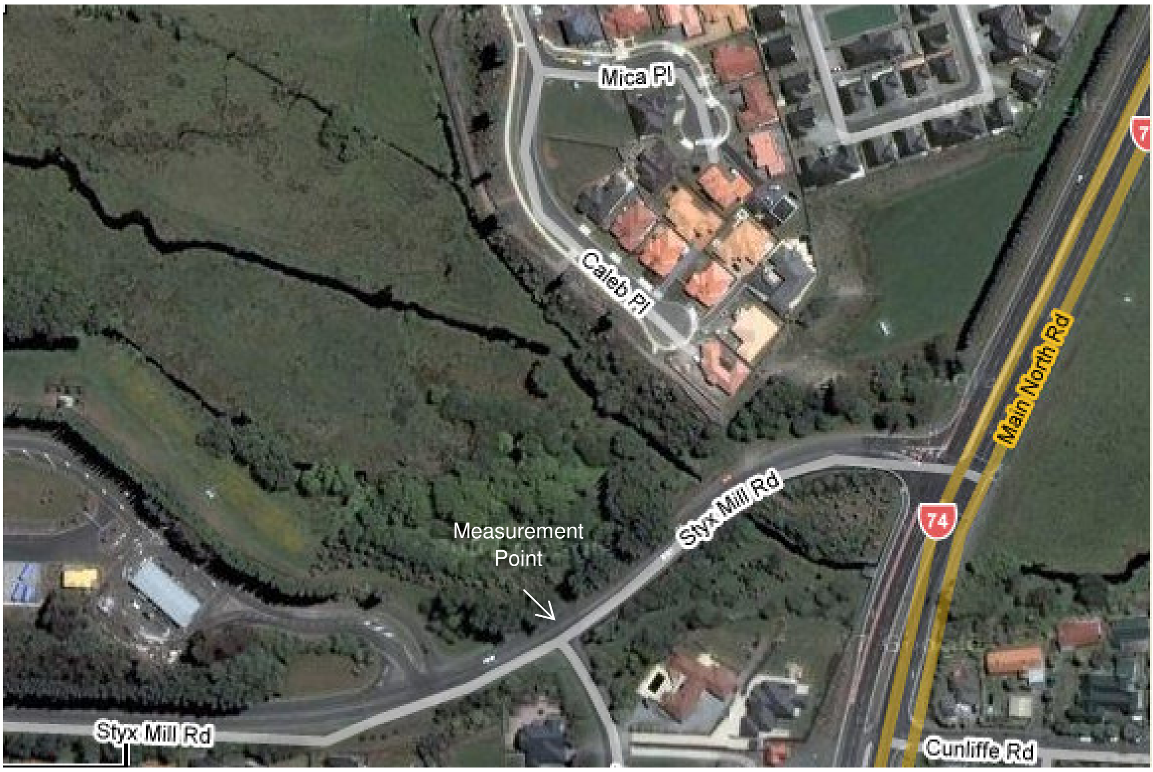

Figure A1: Aerial view of Styx Mill Road Site

A2 Site 2: Constant uphill gradient (noise measurements only)

This site is located on SH1 in a 100 km/h speed zone, 1.065 km north of the Leithfield turnoff heading south towards Woodend.

The linear referencing of the site's start and end locations are:

Location	SH001S/ RS 284
Start point	14180 m heading north
Finish Point	13852 m heading north

Distinguishing features of the site:

Road Surface	Grade 3 Chipseal
Texture Depth	1.9 mm MPD
Lane Roughness	53 NAASRA counts/km
Max. Deflection	n/a
Av. Gradient	2.9% (Maximum = 4.6%)
Carriageway	Single heading into a right hand bend signposted with a 85 km/h curve advisory speed

Figure A2: Approximate start and finish points for Site 2

Figure A3: Panoramic view of Site 2

A3 Site 3: Smooth asphaltic concrete surfaced road in urban (50 km/h) setting (Noise and vibration measurements)

This site is located on SH1 (Main North Road, Woodend) in a 50 km/h speed zone, between Woodend and Hewitts Roads.

The linear referencing of the site's start and end locations are:

Location	SH001S/ RS 311
Start point	5440 m heading north
Finish Point	5135 m heading north

Distinguishing features of the site:

Road Surface	Ultra thin asphaltic concrete (UTA)
Texture Depth	0.9 mm MPD
Lane Roughness	37 NAASRA counts/km
Max. Deflection	0.38 mm under 40 kN FWD impact load (SNP = 4.40)
Gradient	-0.5% to 1%
Carriageway	Single, in good condition. About 200 m north of site speed limit changes from 50 km/h to 70 km/h.

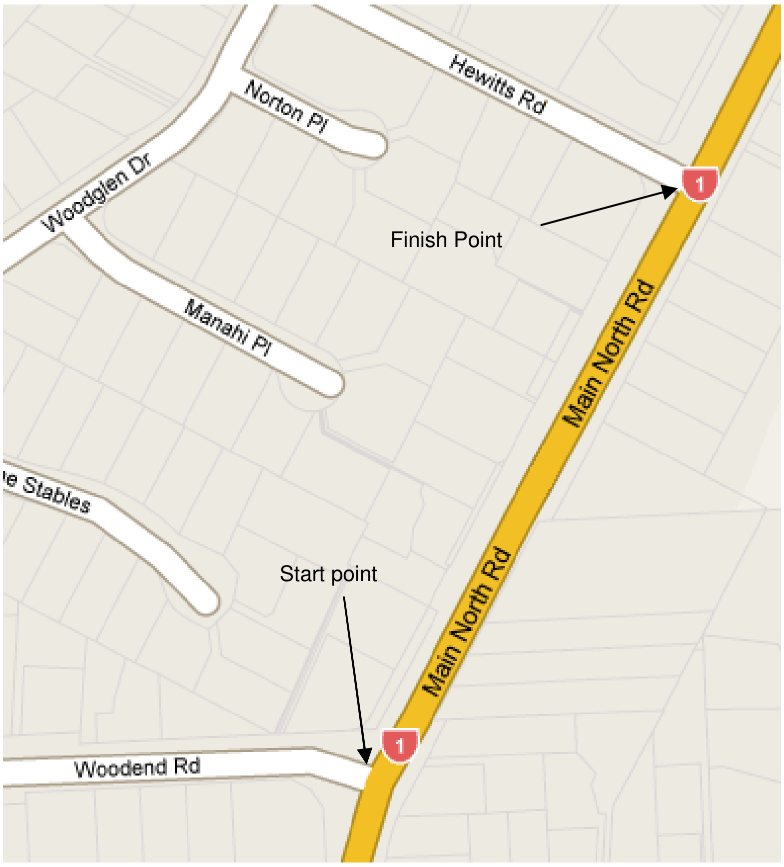

Figure A4: Approximate start and finish points for Site 3

Figure A5: Panoramic view of Site 3

A4 Site 4: Smooth OGPA surfaced road in rural (90 km/h) setting (Noise and vibration measurements)

This site is located on Russley Road (SH1) between Avonhead Road and Memorial Avenue roundabout.

The linear referencing of the site's start and end locations are:

Location	SH001S/RS332 (File:0-11900m)
Start point	9270 m heading north
Finish Point	8560 m heading north

Distinguishing features of the site:

Road Surface	OGPA
Texture Depth	1.02 mm MPD
Roughness	50 NAASRA counts/km
Max. Deflection	0.44 mm under 40 kN FWD impact load (SNP = 4.13)
Gradient	0.2%
Carriageway	Single, in good condition. There are some open areas along the road suitable for setting up the monitoring equipment and a good safety zone for personnel.

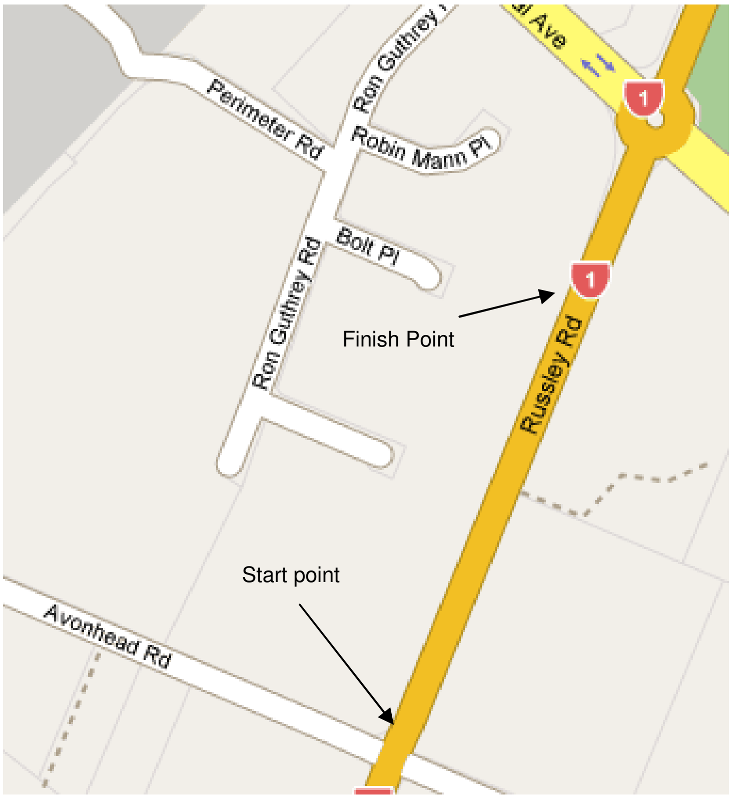

Figure A6: Approximate start and finish points for Site 4

Figure A7: Panoramic view of Site 4

A5 Site 5: High to moderate deflecting chipseal surfaced road in rural (90 km/h) setting (Noise and vibration measurements)

This site is located on Main North Road (SH1), just north of Broad Road, Saltwater Creek.

The linear referencing of the site's start and end locations are:

Location	SH001S/RS 303
Start point	3500 m heading north
Finish Point	3300 m heading north

Distinguishing features of the site:

Road Surface	Grade 3/5 chipseal
Texture Depth	2.3 mm MPD
Lane Roughness	47 NAASRA counts/km
Max. Deflection	0.5 mm – 0.9 mm under 40 kN impact load (3.0 ≤ SNP ≤ 4.2)
Gradient	0.4%
Carriageway	Single, which displays moderate deflection under commercial vehicle tyre loads.

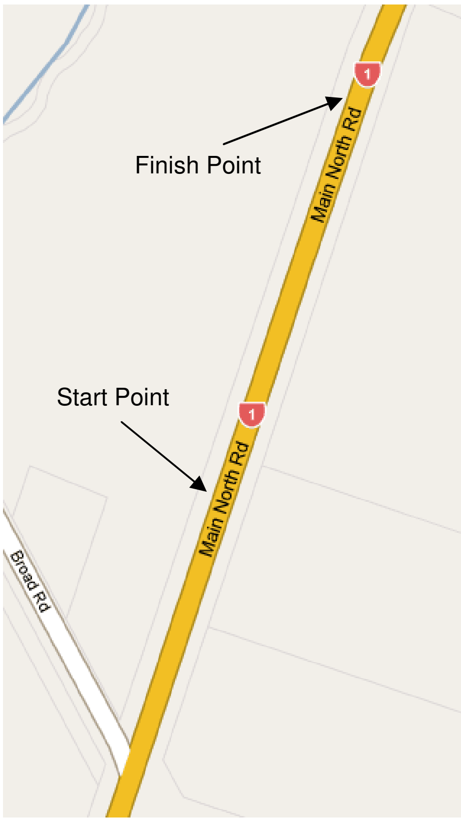

Figure A8: Approximate start and finish points for Site 5

Figure A9: Panoramic view of Site 5

Appendix B: Detailed results

B1 Ground Borne Vibrations

Unloaded		Peak Vertical Acceleration (m/s^2) Mean	95% Confidence Level	Number of Trucks	Mean Speed (km/h)
Site 1		-		0	
Site 2		-		0	
Site 3		0.109	0.056	18	45.0
Site 4		0.101	0.023	22	*60.8
Site 5		0.277	0.099	21	83.8

Loaded		Peak Vertical Acceleration (m/s^2) Mean	95% Confidence Level	Number of Trucks	Mean Speed (km/h)
Site 1	44 Tonne	-		0	
	49 Tonne	-		0	
Site 2	44 Tonne	-		0	
	49 Tonne	-		0	
Site 3	44 Tonne	0.143	0.029	8	*46.5
	49 Tonne	0.118	0.024	3	*46.0
Site 4	44 Tonne	0.070	0.022	4	*53.0
	49 Tonne	0.046	0.004	18	62.1
Site 5	44 Tonne	0.302	0.120	9	83.6
	49 Tonne	0.318	0.101	10	80.1

B2 Drive-by Noise

Unloaded		Equivalent noise level, 100ms (dBA)		Number of Trucks	Mean Speed (km/h)
		Mean	95% Confidence Level		
Site 1		-		0	
Site 2		92.5	1.07	14	82.0
Site 3		84.8	0.83	19	45.0
Site 4		85.0	1.83	22	*60.8
Site 5		89.4	1.60	21	81.9

* *The speed of some vehicles was not recorded. Where the mean speed is calculated from fewer samples than shown in the "number of trucks", the mean speed is marked with an asterisk.*

Loaded		Equivalent noise level, 100ms (dBA)		Number of Trucks	Mean Speed (km/h)
		Mean	95% Confidence Level		
Site 1	44 Tonne	84.3	0.39	2	18
	49 Tonne	85.3	2.74	2	24
Site 2	44 Tonne	94.0	1.22	7	85
	49 Tonne	93.6	0.77	9	85
Site 3	44 Tonne	80.6	1.23	4	46
	49 Tonne	80.4	0.93	6	46
Site 4	44 Tonne	78.9	2.52	3	*47.0
	49 Tonne	79.0	2.36	18	62.1
Site 5	44 Tonne	95.1	4.76	6	84.3
	49 Tonne	90.8	4.31	6	74.5

Appendix C: License Plates of Canterbury Waste Services Trucks Participating in the MOT's Higher Mass Trial

License plates of Canterbury Waste Services trucks with a gross vehicle mass permit of 49 tonnes:

- CNS 814
- CNS 816
- CNS 817
- CPW 743
- CPW 759
- CQG 431
- DBR 775

OPUS