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1976/27. Subsurface conditions at Inveresk, Launceston.

C.J. Knights

PART 1. EFFECTS ON CONSTRUCTION

At the end of the Pleistocene, between 10 000 and 6000 years ago the sea level rose by 100 m, drowning the valleys of the Tamar and South Esk Rivers. These ceased to be fast flowing, rapidly eroding rivers and became sluggish, depositing their sediment loads in the channels and slowly building the marshy flat lands of areas such as North Launceston, Inveresk and Riverside.

Present swamp deposits are up to 30 m thick in the vicinity of Inveresk. Drill logs from Tea Tree Bend and from various works in Launceston, indicate that the sediments are variable, with soft to very soft clays (often organic), intersected by lenses of sand, silt and gravel which may be medium-dense, or loose in nature.

Shallow site investigation by the Public Works Department in Inveresk found that a 0.3 to 1.5 m thick crust of rubble fill is underlain by highly plastic clay with moisture contents ranging between 62% and 103%. The deepest hole, to 9 m, penetrated highly plastic, silty clay with no sand or silt, being intersected. Groundwater is generally about one metre below surface.

A ridge of Tertiary sediments running approximately east-west occurs near Mayne Street. These sediments generally consist of overconsolidated clays with subsidiary sands, laterites and gravels.

CONSTRUCTION DIFFICULTIES

The rubble crust distributes the load of any building but works of any size on the swamp area of Inveresk may encounter difficulties including:

(1) Long term settlement, caused by consolidation of underlying clays.
(2) Differential settlement, due to variations in the clay or the presence of a sand lense or uneven thickness of the rubble crust.
(3) Ground failure from overloading weak clays or silts.
(4) Rapid settlement of loose, clean silts or sands when subject to vibration.

Generally domestic housing should be of a light and flexible construction. Brick buildings are not recommended as these will also settle and may severely crack.

For heavy or rigid structures where settlement is not acceptable, site investigation and engineering designed foundations are required. Account should also be taken of possible effects on adjacent buildings.

Any proposed industry which will generate large vibrations should be carefully considered . If it should be sited over, or near, a lense of loose, clean silt or sand it could cause rapid settlement to occur. As vibrations attenuate very slowly in saturated swamp sediments, any such works should be kept well away from residential areas.

The Tertiary sediments are less difficult as a foundation material. They are not normally prone to settlement, and the most likely difficulty is caused by areas of very plastic clays which have a high shrink-swell potential. As these clays swell in winter and shrink in summer, buildings with inadequate foundations tend to crack.

PART 2. TRAFFIC VIBRATIONS IN INVERESK

During the Inveresk area study (1976), a number of residents complained of the effects of traffic generated vibrations. Inveresk is built on saturated Quaternary clay with lenses of sand, silt and gravel. These materials transmit vibrations to a greater extent than is normal, and several residents have commented on the movement of objects in their homes as trucks passed.

At present Inveresk is a mixed industrial and residential area, but it has been suggested that the area be divided into separate zones, with commercial traffic restricted to using certain streets. For this investigation traffic vibrations were measured at six sites (fig. 1). This enabled some assessment to be made of the effects of variations in grade of road, type of substrata, size of vehicle and speed of vehicle and attentuation factors.

Two three-dimensional vibration sensors which have constant response for frequencies between 14 Hz and 300 Hz were used in this study. The results were fed into a six channel recorder with light sensitive paper, providing a permanent record.

Many of the measurements taken were of vibrations with frequencies of less than 14 Hz, and corrections for this were made by using the frequency response curves provided by the manufacturers. The results are not considered reliable for frequencies of less than 10 Hz.

VEHICLES AS A SOURCE OF VIBRATION

Measured vibration amplitudes will depend on the original vibration generated by the vehicle, on the attenuation characteristics of the road and substrata and also on factors such as whether vibrations coming from each wheel interact in phase or out of phase.

For most roads the largest vibrations are generated by 'bounce loading', as vehicles bounce over irregularities in the pavement. In Inveresk low frequency 'rolling vibrations', generated by each wheel may also be important. Vertical vibrations usually predominate, but parallel vibrations are significant at some sites, and resolved readings were used to calculate the values.

RESULTS

The terms used in this investigation are:

A = amplitude of vibration, measured in particle velocity, mm/s
Av = amplitude of vertical vibrations.
Ahp = amplitude of horizontal vibrations moving parallel to the line of vibration travel.
Aht = amplitude of horizontal vibrations moving transverse to the line of vibration travel.

α = attenuation constant in the formula

$$\log_e \frac{A_2}{A_1} = -\alpha x$$

where x = distance in metres between the readings for A_1 and A_2
f = frequency in cycles/sec (Hz)
K = value for assessing the effect of vibrations on humans

The results are summarised below. Full results are given in Appendix 1.

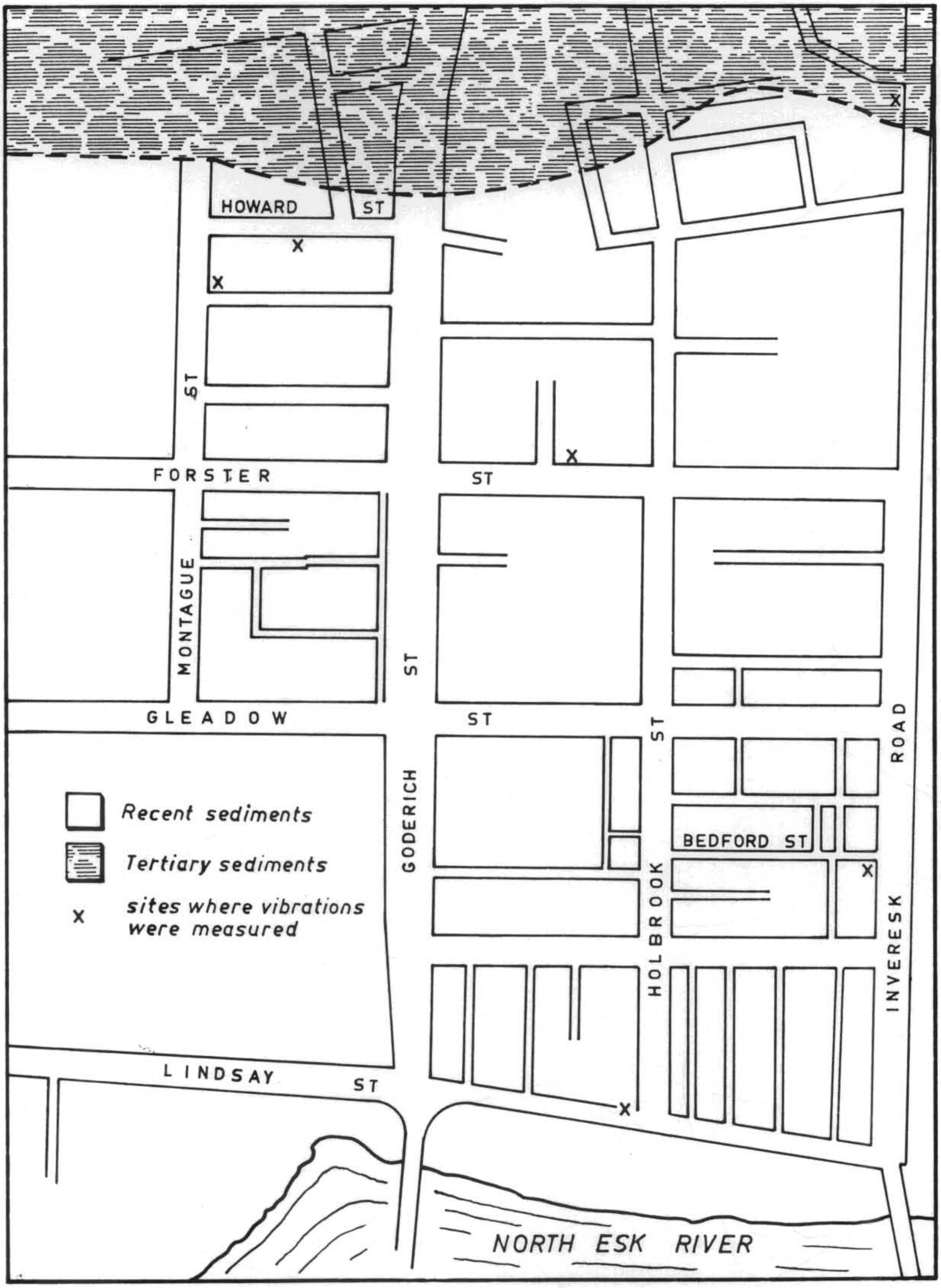

Figure 1. *Location of vibration measurement sites, Invenesk.*

5 cm

19 Howard Street

Av predominates. Ahp is 0.5 to 0.8 x Av.
Dominant frequencies 10-15 Hz.
Attenuation, between 0-7 m; α = -0.082 average.
Old 6-tonne truck produced greater vibrations than a modern 10-tonne truck.
Highest kerb-side reading = 1.24 mm/s.
Highest house-front reading = 0.88 mm/s.
Highest resolved K = 0.86.

18 Montague Street

Av predominates. Ahp significant.
Dominant frequencies 3-17 Hz.
Low frequencies predominate with distance attenuation. For heavy truck α = 0.045 average. For light trucks the amplitude appeared to increase with distance, however this may be due to the inaccuracies of measuring low frequency signals.
Heavy vehicle generated greatest vibrations.
Highest kerb-side reading = 1.9 mm/s.
Highest house-front reading = 0.88 mm/s.
Very low frequency roll noted.
Highest resolved K = 0.58

Lindsay Street

Av predominates. Ahp about 0.3 x Av
Dominant frequencies 12-16 Hz.
Attenuation between 0 and 5 m; α = -0.057 average.
Heavy trucks generally generate considerably greater vibrations than light trucks.
Highest kerb-side reading, Av = 1.2 mm/s.
Highest house-front amplitude Av = 0.9 mm/s.
Highest resolved K = 0.8.

52 Forster Street

Av predominates. Aht and Ahp are insignificant.
Dominant frequencies 12 to 18 Hz.
Attenuation, between 5 and 10 m; α = -0.026 average.
between 5 and 16 m; α = -0.069 average.
Av for heavy trucks is two to seven times Av for light (6-10 tonne) trucks.
Highest kerb-side reading = 0.78 mm/s.
Highest house-front level = 0.78 mm/s, although normal readings = 0.3 to 0.4 mm/s.
Highest resolved K = 0.6

Corner of Bedford Street and Invermay Road

Av predominates.
Dominant frequencies 10 to 15 Hz, mostly 10 Hz.
Attenuation, between 0 and 17 m; α = 0.08.
between 4 and 17 m; α = -0.056
between 8 and 17 m; α = -0.0422
Light trucks generated similar vibration levels to heavy trucks.
Highest kerb-side reading = 1.4 mm/s.
Highest house-front reading = 1.4 mm/s.
Highest resolved K = 1.

189 Invermay Road

Av predominates. Ahp is 0.3 to 0.5 x Av.
Dominant frequency30-35 Hz.
Attenuation, between 0 and 10 m; α = -0.139.
Heavy tankers generate two to three times vibrations of light trucks.
Highest kerb-side reading = 1.45 mm/s.
Highest house-front reading = 0.31 mm/s.
Highest resolved K = 0.3.

DISCUSSION

It was reported by residents that heavy trucks passed by their houses at a particular time of day or night; therefore the heaviest vehicles to use a particular road were often not recorded and some interpolation is needed from site to site. The term light truck is used to indicate a vehicle of less than 10 tonnes while heavy truck is used to indicate a large three axled truck or tanker. Heavy vehicles generally induced greater vibrations than light vehicles, except at the corner of Invermay Road and Bedford Street, where the generated amplitudes appear to be similar.

Dominant frequencies on the flats are in the range of 10 to 18 Hz. This compares with dominant frequencies of 30 to 35 Hz on the Tertiary sediments at 189 Invermay Road. At the Montague Street site, conditions are unusual and dominant frequencies are in the range of 3 to 7 Hz. A low frequency roll of 0.25 Hz was noted to continue unattenuated for at least 8 seconds after a heavy vehicle had passed. Both the kerb-side and the 10 m geophone recorded this effect in the vertical mode, although owing to the frequency limitations of the geophones the amplitude of this roll cannot be assessed. The amplitude may well be quite large and continue for a significant time. Before Montague Street is considered as a road for commercial traffic, this low frequency roll should be further investigated with suitable equipment.

On the flats, the attenuation constant α is between -0.026 and 0.08. On the Tertiary sediments at 189 Invermay Road attenuation is more rapid with α = -0.139. At Montague Street the vibration amplitudes appeared to actually increase at the distant geophone.

Vibrations generated by bounce loading increase rapidly with vehicle speed. This may be seen particularly at Howard Street (appendix 1) and was generally observed. Amplitudes of vibrations may be doubled or trebled by the effects of a bumpy road surface.

Quality of road construction is an important factor in determining the vibrations which are transmitted into the substrata. Although Forster Street is subject to very heavy traffic, the level of vibration was comparatively low. Montague Street and Howard Street are not suitable for heavy vehicles.

DAMAGE LEVELS FOR BUILDINGS

Many authorities have worked on, and suggested damage levels for buildings. Generally it is agreed that humans are sensitive to vibrations and that vibrations must become personally intolerable to the occupants of a building before there is risk of structural damage. Recent information on levels of vibration required for damage to occur is given in the draft revision of the German Standards Institute. This specifies maximum allowable resultant velocities for 'buildings with existing defects' equal to 5 mm/s.

The level of traffic vibrations recorded in Inveresk is unlikely to cause damage to buildings, except in the special situation of a new or upgraded road being located near a buried lense of clean silt or sand. In such a situation rapid settlement may be caused which would damage the buildings above.

HUMAN SENSITIVITY TO VIBRATIONS

This may be assessed in terms of *K* values. Using the method described in the draft revision of the German Standards Institute (1970) *K* is calculated as:

$$K = \frac{0.8\, f}{\sqrt{100 + f^2}}$$

At each site the maximum resolved *K* at house frontage has been calculated, and is included under the summary of results.

A table of *K* levels, acceptable for various situations is shown in Table 1. Values given in brackets apply to cases where the frequency is below 15 Hz.

At all sites except 189 Invermay Road, the *K* value of house frontage is higher than, or considerably higher than that acceptable for 'repeated vibrations occurring in mixed areas' during day night or night. The maximum *K* value for Forster Street is only marginally over the level and for most vehicles it is well below the level necessary to make it unacceptable for day time situations. However at Invermay Road/Bedford Street, Lindsay Street, Montague Street and Howard Street, the maximum *K* value is equal to, or higher than, the figure for 'business and industrial areas' in day time; all are unacceptable for night.

Table 1. LEVELS OF VIBRATION ACCEPTABLE FOR VARIOUS SITUATIONS (AFTER DRAFT REVISION OF DIN 4150).

Building areas	Time	Permissible intensities or *K* value		
		Sustained vibrations	Repeatedly vibrations occurring	Seldom occurring shocks
Health resorts, Hospitals, Nursing homes (SO)	Day	Threshold of perception	Threshold of perception	2.5
	Night			Threshold of perception
Small building estates (WS) Purely residential areas (Wh) General residential areas (WA) Weekend living areas (SW) University areas (SO)	Day	Threshold of perception	0.2 (0.1)	4
	Night		Threshold of perception	Threshold of perception
Village areas (MD) Mixed areas (Ml) Central areas (MK)	Day	0.3 (0.15)	0.63 (0.3)	8
	Night	Threshold of perception	Threshold of perception	Threshold of perception
Business areas (GE) Industrial areas (Gl) Port areas (SO)	Day	0.63 (0.3)	0.8 (0.4)	12
	Night	0.4	0.4	0.4

CONCLUSIONS

House damage is unlikely to be caused by traffic vibrations in the Inveresk area. However residents are being subjected to levels of vibration which are considered unacceptable for mixed residential and industrial areas.

Owing to the unusual substrata, combined with the close proximity of commercial and residential interests, it seems inevitable that residents will suffer some disturbance from traffic vibrations. Disturbance to residents can be lessened by restricting commercial traffic, especially heavy vehicles, to certain specified roads. Vibrations from these roads can then be minimised by having sound road construction and maintaining a smooth riding surface. Consideration may be given to the use of low speed limits, especially at night.

It was noted in Howard Street that even light trucks, when driven at speed on a residential grade road, do cause unacceptable levels of vibration.

At the Montague Street site heavy vehicles appear to cause a low frequency roll of unknown amplitude and duration.

For the flats, the attenuation constant α is between -0.026 and 0.08.

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[28 May 1976]

APPENDIX 1

Vibration measurements at Inveresk

19 HOWARD STREET

Av	Ahp	Aht	Hz	Av	Ahp	Aht	Hz	$\frac{Av_2}{Av_1}$	Remarks
Geophone 1 at kerb.				*Geophone 2 at 7 m.*					
0.35	0.12	-	15	0.15	-	-	15	0.43	10 tonne truck, 15 km/h
0.4	0.25	0.35	15	0.25	0.2	-	15	0.62	20 km/h
1.0	0.7	0.1	20	0.6	0.3	-	15	0.6	30 km/h
2.0	0.85	0.5		0.7	0.37	0.13		0.35	45 km/h
0.44	0.38	0.27	12	0.34	0.16	-	12	0.77	6 tonne truck, starting
1.15	0.81	0.16	12	0.56	0.27	-	12	0.49	16 km/h
1.25	1.0	0.13	14	0.9	0.5	-	12.5	0.7	32 km/h
1.24	1.0	0.5	10	0.7	0.2	-	10	0.56	Cement truck, 40 km/h
Geophone 1 on porch, at 10 m.									
0.32	-	0.06	11	0.9	0.58	0.17	11		10 tonne truck, 30 km/h
0.88	0.4	0.24	10	1.1	0.44	0.1	10		6 tonne truck, 48 km/h

18 MONTAGUE STREET

Av	Ahp	Aht	Hz	Av	Ahp	Aht	Hz	$\frac{Av_2}{Av_1}$	Remarks
Geophone 1 at kerb.				*Geophone 2 at 17 m.*					
0.4	-	-	15	0.05	-	-	15		1 tonne truck slow.
1.44?	-	-	5	0.4?	-	-	5		10 tonne truck, 20 km/h
1.9	0.9	-	12	0.88	0.52	-	7	0.46	Heavy truck, 20 km/h
0.25 Hz roll of significant amplitude									Low frequency roll.
0.4	0.36	0.28	12	0.72?	-	-	5		10 tonne truck, 30 km/h
0.4	0.22	-	17	1.0?	-	-	3		10 tonne truck, 40 km/h

LINDSAY STREET

Av	Ahp	Aht	Hz	Av	Ahp	Aht	Hz	$\frac{Av_2}{Av_1}$	Remarks
Geophone 1 at kerb.				*Geophone 2 at 5 m.*					
1.1	0.36	0.16	12	0.78	0.16	0.13	12	0.7	Petrol tanker.
0.75	0.19	0.3	16	0.6	0.19	-	16	0.78	Tanker over road.
1.1	-	0.32	12	0.44	-	0.12	12	0.4	Small truck.
0.7	-	-	13	0.46	-	-	13	0.65	Empty truck.
1.2	0.25	0.25	15	0.9	0.25	0.25	15	0.75	Empty truck.
0.9	0.22	0.2	15	0.67	0.18	0.2	15	0.75	Bus.
0.24	-	-	10	0.24	-	-	10	1	Slow truck.
0.2	-	-	15	0.1	-	-	15	0.5	Light truck.
0.16	-	-	15	0.02	-	-	15	0.125	Light truck

52 FORSTER STREET.

Av	Ahp	Aht	Hz	Av	Ahp	Aht	Hz	$\frac{Av_2}{Av_1}$	Remarks
Geophone 1 at Kerb.				*Geophone 2 at 5 m.*					
0.65	0.13	0.65	14	0.18	0.09	-	14		Big empty truck.
0.11	-	-	18	0.15	-	-	16		Other side of road.
0.35	-	-	18	0.22	-	-	18		Empty truck.
0.5	-	-	18	0.4	-	-	18		Log truck.
0.56	-	-	12	0.5	-	-	10		Container truck.
0.09	-	-		0.06	-	-			Light truck ≃ 6 tonnes.
0.1	-	-	15	0.1	-	-	15		Light truck.
0.34	0.09	-	15	0.3	0.1	-	15		Heavy gravel truck.
0.35	0.14	-	15	0.35	0.14	-	15		Slow truck.
				Geophone at 10 m.					
0.78	0.12	-	13	0.78	0.16	-	13		Heavy truck.
0.2	-	-	15	0.2	-	-	12		Big gravel truck.
0.27	-	-	15	0.28	-	-	12		Slow truck.
Geophone 1 at 5 m.				*Geophone 2 at 10 m.*					
0.31	0.13	0.09	15	0.22	0.07	-	15	0.7	Heavy truck.
0.36	-	-	12	0.36	-	-	12	1.0	Light truck.
0.4	-	-	12	0.36	-	-	12	0.9	Light truck.
0.36	0.16	-	12	0.3	-	-	12	0.83	Empty truck.
0.4	-	-	18	0.355	-	-	15	0.89	Tanker, other side.
0.31	-	-	15	0.31	-	-	15	1.0	Tanker, other side.
Geophone 1 at 5 m.				*Geophone 2 at 16 m.*					
0.18	-	-	15	0.09	-	-	15	0.5	Container truck.
0.27	-	-	15	0.11	-	-	15	0.41	Container truck.
0.18	-	-	16	0.09	-	-	16	0.5	Light truck.
0.3	-	-	16	0.135	-	-	16	0.45	Light truck.

189 INVERMAY ROAD

Av	Ahp	Aht	Hz	Av	Ahp	Aht	Hz	$\frac{Av_2}{Av_1}$	Remarks
Geophone 1 at kerb.				*Geophone 2 at 10 m.*					
1.45	0.45	0.38	35	0.22	0.11	0.08	35	0.15	Tanker.
0.62	0.22	0.22	30	0.155	0.145	0.08	30	0.25	Heavy truck.
1.3	0.7	0.18	30	0.2	0.09	-	30	0.155	Heavy empty truck.
1.05	0.45	0.22	35	0.31	0.18	0.08	30	0.3	Slow heavy truck.
0.4	0.215	0.1	45	0.1	0.09	-	35	0.22	Slow truck.
0.62	0.31	0.18	40	0.12	0.11	0.045	30	0.19	Bottle truck.
0.45	0.22	0.08	35	0.08	-	-	35	0.175	Truck.
0.53	0.35	-		0.18	0.11	0.045		0.21	Heavy trailer.
0.35	0.27	-	30	0.15	0.1	-	30	0.43	Bus.
0.52	0.17	0.06		0.2	0.11	0.08		0.39	Heavy trailer.

CORNER BEDFORD STREET and INVERMAY ROAD

Av	Hz	Av	Hz	$\frac{Av_2}{Av_1}$	Remarks
Geophone 1 at kerb.		*Geophone 2 at 17 m.*			
0.57	2	0.15	15	0.26	Truck.
0.51	12	0.17	12	0.33	Light truck.
0.8	10	0.22	12	0.28	Unloaded bus.
0.7	10	0.18	10	0.26	Light truck.
0.7	10	0.14	10	0.2	Light truck.
0.68	12	0.12	12	0.18	Heavy truck.
0.9	10	0.26	10	0.29	Bus.
0.26	10	0.35	10		Truck other side of road.
1.4	10	0.32	10	0.23	Light fast truck.
Geophone 1 to 4 m.					
0.17	12	0.13	10	0.77	Other side.
1.4	10	0.36	10	0.25	Empty transporter.
0.66	10	0.33	10	0.5	Container.
0.93	12	0.38	12	0.41	Light fast truck.
Geophone 1 to 8 m.					
0.32	10	0.25	10	0.77	Light truck.
0.11	15	0.11	15	0.8	Slow truck on Robert St
0.27	10	0.31	10	1.15	Light truck.
0.32	10	0.18	10	0.57	Slow empty van.
0.45	10	0.27	10	0.6	Bus.
Geophone 1 to 17 m together.					
0.32	12	0.32	12		Heavy truck.