Proceedings of The Institute of Acoustics

TRAFFIC INDUCED VIBRATION IN DWELLINGS - RESULTS OF A JURY EXPERIMENT

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INTRODUCTION

Traffic induced vibrations in residential properties is a widespread problem. Studies have shown that where the road surface is not uneven the vibration effects such as doors and windows rattling or buzzing and floors shaking or trembling are caused by low frequency airbourne sound pressure waves generated by passing vehicles[1,2]. The aim of the present study was to gain a better understanding of the relationship between noise levels and building vibration levels and disturbance. One objective was to determine scales of noise which were highly correlated with vibration disturbance and could be used as a basis for noise emission standards and environmental appraisal. A further objective was to determine vehicle types and their modes of operation which would produce the greatest degree of building vibration and disturbance.

The paper describes a jury experiment where a number of residents made ratings of vibration disturbance inside the front room of a dwelling situated close to a heavily trafficked urban road. Individual vehicle events were selected for vibration assessment and noise and vibration levels were monitored. The analysis involved the correlation of these subjective and objective measures. In a further study without a jury, noise levels at the facade of another house were related to building vibrations to confirm the vehicle effects found in the first study.

SITE SELECTION AND DETAILS

Interviews were held with residents along a number of heavily trafficked roads in Reading and Guildford where a vibration problem was thought to exist. The questions asked were similar to those employed in a previous 50 site survey of vibration disturbance and covered many aspects of the vibration problem[3]. Those residents who were seriously bothered by vibration were invited to host a jury experiment by making the front room of their home available for a day and asking neighbours to the house to take part in assessing vibration disturbance. It was explained that 8 people were required for the jury and that jurors would be paid for their time. From a small number of positive replies a house was selected in Pell Street near the centre of Reading. The house was four and a half metres from a heavily trafficked road (see Fig 1(a)) which had a steep gradient of 9%. It was expected that the gradient would tend to enhance low frequency noise emissions from passing vehicles and hence building vibrations. The distance between the facades of houses on the two sides of the road was only 11 m. This feature was also expected to give rise to high noise and vibration levels because of the additional contribution from reflected noise, ie the 'canyon' effect.

EXPERIMENTAL PROCEDURE

The protocol and rating scale employed had been successfully piloted in a previous jury experiment in Guildford. Seven people were eventually found for the jury at Pell Street, 2 males and 5 females. Their ages ranged from 22 to 73 years, the average being 52 years. They were seated around the edges of the room and were given instructions on how to rate vibration disturbance from individual vehicles passing the house. They were first handed sheets with rating scales set out in rows. A 7 point scale was used viz:-

Not at all bothered								Extremely bothered

This was very similar to the scale used in the previous survey[3].

It was explained that there were many possible vibration effects that they could take into account when making their judgements. These included windows, doors, or bric and brac rattling or buzzing, floors shaking or trembling as well as the direct perception of the vibration through the stimulation of body parts (eg chest wall). They were asked to imagine that they were attempting to relax in the room and after experiencing the vehicle event to tick the part of the scale that best reflected how bothered they might have been by the vibration. In the previous jury experiment it was found that ratings of vibration disturbance and ratings of the noticeability of the vibration were highly correlated (r=0.89). Vehicle pass-by events were selected by an assistant positioned outside the house who was in contact with the experimenter inside the house by headsets. The vehicles were selected such that they were reasonably isolated from the rest of the traffic. In this way the jury were presented with individual vehicle events to rate and the measurements of sound and vibration used to physically characterize each event were not substantially affected by the noise emissions from other vehicles. For each event, the experimenter alerted the jury to an approaching vehicle by activating a light positioned on the mantlepiece. The panel were instructed to rate any vibration they experienced during the 5 sec period when the light was on and to keep quite still and quiet. This was necessary to keep extraneous noise and vibration to a minimum. The ratings were made on the next unused scale directly after the light was switched off.

INSTRUMENTATION

The approximate positions of the noise and vibration transducers are shown in Fig 1(a)). Outside the house a 1/2 inch condenser microphone with windshield was placed 1 m from the facade at a height of 1.2 m. Inside a similar microphone was set up at a height of 1.2 m in the centre of the room and directly underneath a large accelerometer (sensitivity 10V/g) attached to a small plate was placed on the carpet. Another accelerometer (sensitivity 40mV/g) was attached to the middle of the top pane in the centre window. The signals from the tranducers were conditioned by appropriate preamplifiers and measuring amplifiers and recorded on separate FM channels of a Racal 7D tape recorder running at 15 inch/s. The tape recorder gives a 'flat' response from DC to 4kHz. The tape recorder was switched on at the beginning of each event and switched off after the light was extinguished. In this way a record of the noise and vibration occurring during each event was taken over the same time period as the jury were asked to give a rating. During each event a manual record was made of the type of vehicle and its operating condition.

ANALYSIS

There were 127 events which were successfully analysed. For each event the maximum and Leq levels for the various acoustic and vibration measures were computed for the 5 second assessment period. A digital 1/3 octave signal analyser was used to produce in real time the frequency spectra during the events. The exponentially averaged period was set at 0.25s (fast response) and in addition two channels were reserved for displaying 2s exponentially averaged periods (slow response) for the linear (25 to 4kHz and 5 to 500 Hz) and A-weighted levels. The spectra were sampled every 50 ms over the 5s period and stored in a minicomputer memory. The computer was programmed to calculate the following measures from the noise recordings. The maximum and Leq levels for the 63 and 80 Hz octaves, the linear levels (40 to 125 Hz and 25 to 4kHz) and the A, B and C weighted levels. In addition the maximum slow averaged linear (25 to 4kHz) and A-weighted levels were computed. For the window and floor vibration records the maximum Leq values for the 63 and 80 Hz octaves and the linear levels (40 to 125 Hz and 5 to 500 Hz) were determined using 0.25s averaging and in addition the slow averaged linear level (5 to 500 Hz) was computed.

Two types of analyses were performed. Firstly correlational analysis was used to examine relationships between the median vibration disturbance scores for each vehicle event with the corresponding noise and vibration levels. Secondly, the pass-by events were sorted by vehicle type and operating condition and maxima, minima and average values were computed to investigate the effects on disturbance and vibration levels of different types of vehicle.

FURTHER EXPERIMENT

In this further study the aim was to gather more information on the effects of different vehicle types on building vibration to confirm the results obtained at Pell Street. A further dwelling where the householder had complained of vibration was found in Mount Pleasant close to a 2 lane one-way system near the centre of Reading. It was not possible to hold a jury experiment at this site. Although the gradient outside the house was only 2.5% it increased substantially a little further along the road and vehicles were often found to be accelerating past the site because of traffic lights at the bottom of the hill. The facade was only 5 m from the kerb and the interfacade separation was 15 m. The experimental procedure was very similar to that used at Pell Street. Microphones and accelerometers were located in similar positions (see Fig 1(b)). Vibration and noise recordings were made of the passage of vehicles travelling freely and notes were kept of the types of vehicle and their operating characteristics. Using the analysis described above the maximum levels of noise and vibration measures were determined for each vehicle event.

TRAFFIC INDUCED VIBRATION IN DWELLINGS - RESULTS OF A JURY EXPERIMENT

RESULTS

From 1/3 octave analysis of vehicle events at both sites it was found that window and floor vibration levels were generally highest in the band 40 to 125 Hz. Vibrations in these frequency ranges were caused by the low frequency noise emission from passing vehicles. These effects were also reported in previous studies[1,2]. Peak levels of window vibration tended to occur at a higher frequency than the peak levels recorded for floor vibration.

At Pell Street the main manifestation of building vibration was window rattle and this was clearly audible during the replay of the interior noise recordings. Examination of the frequency spectra for the floor vibrations showed that there were few events where vibration levels in the middle of the floor exceeded the threshold for human perception[4] and in these cases levels were close to threshold.

Table 1 lists for Pell Street data the correlation coefficients for the noise and vibration measures with the median subjective rating (based on 127 vehicle events) and Table 2 gives the correlations between the outside noise scales and the maximum linear (5-500Hz) level for window and floor vibration at Pell Street and Mount Pleasant. All correlations were statistically significant at the 0.1% level. Generally for a particular column in the tables the range in the values of the correlation coefficients is small and consequently many of the correlations do not differ significantly. Those correlations that differ significantly from the best related measure are indicated.

From Table 1 the measures that are significantly worse than the best correlated scales are based on the 63 or 80 Hz octave. For the outside noise measures the scales best related to the median disturbance ratings are the linear (25-4kHz) and C-weighted scales (r=0.78). Of the inside noise measures the A-weighted scale produced the highest correlation (r=0.74) with the ratings. An inspection of the correlations for window and floor vibration measures showed that in both cases the linear (5-500 Hz) level was most closely associated with subjective ratings (correlations of 0.79 and 0.70 respectively).

For a particular frequency range or weighting the Leq measures produced similar correlations with ratings as did the maximum levels. It was therefore decided to use only maximum levels of noise and vibration in relating outside noise scales to window and floor vibrations (see Table 2). In this analysis the maximum linear (5-500 Hz) level was used as a measure of both window and floor vibration since this measure was most closely related to median ratings. For comparison, correlations were also computed from Mount Pleasant data. At both sites the window vibration level was closely related to the linear level (25-4kHz) and these correlations were significantly different from the A-weighted and 63Hz octave levels. In addition, at Pell Street the B-weighted and 80Hz octave levels differed significantly.

At Pell Street the floor vibration level was most closely associated with the 63Hz octave level but at Mount Pleasant the best correlated measure was the 80Hz octave level. At both sites the A and B-weighted levels differed significantly from the best correlated measure.

The high and low frequency noise emissions of different classes of vehicle were compared by plotting the maximum dB(A) level against the maximum linear (40-125Hz) measure. For those vehicles passing the sites on the nearside at a steady speed (Fig 2(a) and 2(b) it can be seen that some light vehicles produce relatively high levels of low frequency noise.

The effects on vibration disturbance ratings of different types of vehicle irrespective of operating condition and position on the road can be seen in Table 3. The minima, maxima and median ratings are listed for each vehicle type. There is a clear trend for the median disturbance score to increase with vehicle weight. Table 4 shows for each site the effects of vehicle weight and operating conditions on window and floor vibration levels for vehicles passing on the nearside. Testing differences between the averages for heavy and light vehicles operating at a steady speed at Pell Street there were statistically significant differences at the 0.1% level for average ratings and window vibration level but there was no statistical difference in the average floor vibration levels. At Mount Pleasant, both average window and floor vibration levels differed significantly at the 0.1% level. Testing differences between the averages for heavy and light vehicles accelerating it was found that there was no significant difference in floor and window vibration levels but there was a significant difference at the 5% level in average disturbance ratings. At Mount Pleasant there was no significant difference in average floor vibration levels but there was a statistical difference at the 1% level in window vibration levels. Tests on the effects of operating conditions showed that for both light and heavy vehicles there was no statistically significant differences in ratings or vibrations levels for vehicles travelling at a steady speed or accelerating. For Pell Street further tests showed that there were no significant differences between vehicles slowing and travelling at a steady speed. It is probable that real differences would be demonstrated under more controlled tests where the same group of vehicles were operated under various conditions.

DISCUSSION

The correlational analyses confirm the main findings of the 50 site survey that ratings of vibration disturbance are significantly associated with all the noise measures employed and many of these corelations are not significantly different. However in the present study there is a tendency for the external linear noise level (25-4kHz) to be more closely related to vibration disturbance than the weighted levels. This is consistent with the fact that at both sites the window vibration level (which was the main manifestation of vibration) was most closely related to this outside noise measure. Floor vibration levels at sites were most highly correlated to linear or low frequency octave levels of noise and poorly related to A-weighted measures which heavily attenuate the low frequency component. This poor association may be due to the low natural frequency of vibration of the floor. Of the inside noise measures the A-weighted level was best related to disturbance scores. This may result from the fact that parasitic noise is generally at a high frequency and has, therefore, relatively more effect on an A-weighted level than a linear or exclusively low frequency measure. At Pell Street the parasitic noise was caused mainly by window rattle and this effect was likely to result in high ratings.

Heavy vehicles produced on average significantly more disturbance and vibration than light vehicles but there was a considerable range in levels. From Table 3 although the median disturbance scores reflect increasing vehicle weight consistently, maximum ratings were given for some vehicles in all classes except the heaviest category. From Table 4 the maximum floor vibration level at Pell Street was produced by a light vehicle travelling at a steady speed and at Mount Pleasant this maximum level was produced by a light vehicle accelerating. These results are consistent with the finding that some small vehicles produced similar maximum levels of low frequency noise to those produced by heavy vehicles operating under similar conditions. This is clearly demonstrated in Fig 2(a) and to a lesser extent in Fig 2(b).

CONCLUSIONS

1. Results from the jury experiment indicate that vibration disturbance as measured by a rating scale are significantly related to a range of outside noise measures. Since many of the correlations were not significantly different no preferred noise scale for general use in predicting vibration disturbance can be determined solely on the rank order of the correlation coefficients.

2. Heavy vehicles produced on average more vibration and higher disturbance ratings than light vehicles although there was a considerable overlap in the effects of these vehicles.

ACKNOWLEDGEMENTS

The study formed part of the programme of research of the Vehicle Engineering Division of TRRL. The assistance of Messrs. Abbott and Godfrey is gratefully acknowledged.

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Table 1. Correlation coefficients for noise and vibration measures with with median subjective rating

Scales	Noise Measures		Vibration Measures	
	Outside	Inside	Window	Floor
Maximum Levels				
63 Hz octave	0.61*	0.60*	0.65*	0.61
80 Hz octave	0.55*	0.47*	0.69	0.54
Linear 40-125 Hz	0.69	0.63	0.73	0.66
Linear 5-500 Hz	-	-	0.76	0.67
Linear 5-500 Hz (slow)	-	-	0.78	0.68
Linear 25-4kHz	0.74	0.64	-	
Linear 25-4kHz (slow)	0.76	0.68	-	
A Weighted	0.69	0.68	-	
A Weighted (slow)	0.70	0.74	-	
B Weighted	0.71	0.62	-	
C Weighted	0.73	0.63	-	
L_{eq}				
63Hz octave	0.65*	0.64	0.66*	0.61
80 Hz octave	0.60*	0.53*	0.72	0.58*
Linear 40-125Hz	0.74	0.68	0.78	0.68
Linear 5-500Hz	-	-	0.79	0.70
Linear 25-4kHz	0.78	0.71	-	-
A Weighted	0.72	0.72	-	-
B Weighted	0.76	0.69	-	-
C Weighted	0.78	0.70	-	-

* correlation significantly different (at at least the 5% level) from the highest correlation in the column.

Table 2. Correlation coefficients for vibration levels with outside noise measures

Maximum noise level	Maximum linear vibration level 5-500Hz (slow) Window		Floor	
	PELL ST (n=127)	MT. PLEASANT (n=87)	PELL ST (n=127)	MT.PLEASANT (n=87)
63 Hz octave	0.65*	0.62*	0.63	0.75
80 Hz octave	0.66*	0.68	0.44	0.78
Linear 40-125 Hz	0.82	0.69	0.60	0.74
Linear 25-4kHz	0.86	0.73	0.57	0.70
Linear 25-4kHz (slow)	0.88	0.78	0.59	0.72
A Weighted	0.73*	0.63*	0.32*	0.44*
A Weighted (slow)	0.74*	0.70	0.34*	0.50*
B Weighted	0.81*	0.72	0.42*	0.63*
C Weighted	0.85	0.73	0.56	0.71

* Correlation significantly different (at at least the 5% level) from the highest correlation in the column.

Table 3. Subjective ratings of vibration nuisance for different vehicle types (all operating conditions)

Vehicle type	Number of events	Subjective ratings Minimum	Maximum	Median
Heavy goods vehicles (3 axles or more)	7	4	6	6
Medium goods vehicles (2 axles)	34	2	7	5
Buses and coaches	14	2	7	4
Cars and light goods vehicles	72	1	7	3

TABLE 4

Vibration levels and ratings by vehicle category and operating condition

Site	Vehicle Category	Operating Conditions	Number of Events	Average Rating	Vibration level† (mm.s^{-2})					
					Window			Floor		
					Minimum	Maximum	Average	Minimum	Maximum	Average
Pell St.	Heavy*	Steady Speed	12	5.83	174	1,429	501	5.5	52	15
		Accelerating	10	5.20	200	1,135	407	6.9	69	19
	Light**	Steady Speed	23	3.91	57	881	216	2.8	69	10
		Accelerating	7	3.57	124	708	269	3.2	32	9.3
Mt.Pleasant	Heavy	Steady Speed	11	-	422	3,273	1,000	2.6	13	5.0
		Accelerating	15	-	403	1,531	813	1.7	9.8	4.6
	Light	Steady Speed	17	-	127	724	305	1.0	9.8	2.4
		Accelerating	13	-	232	1,514	457	1.3	25	3.5

† Maximum linear level (5-500 Hz)

* Heavy vehicles include all goods vehicles (except light vans) buses and coaches

** Light vehicles includes cars and light vans

TRAFFIC INDUCED VIBRATION IN DWELLINGS - RESULTS OF A JURY EXPERIMENT

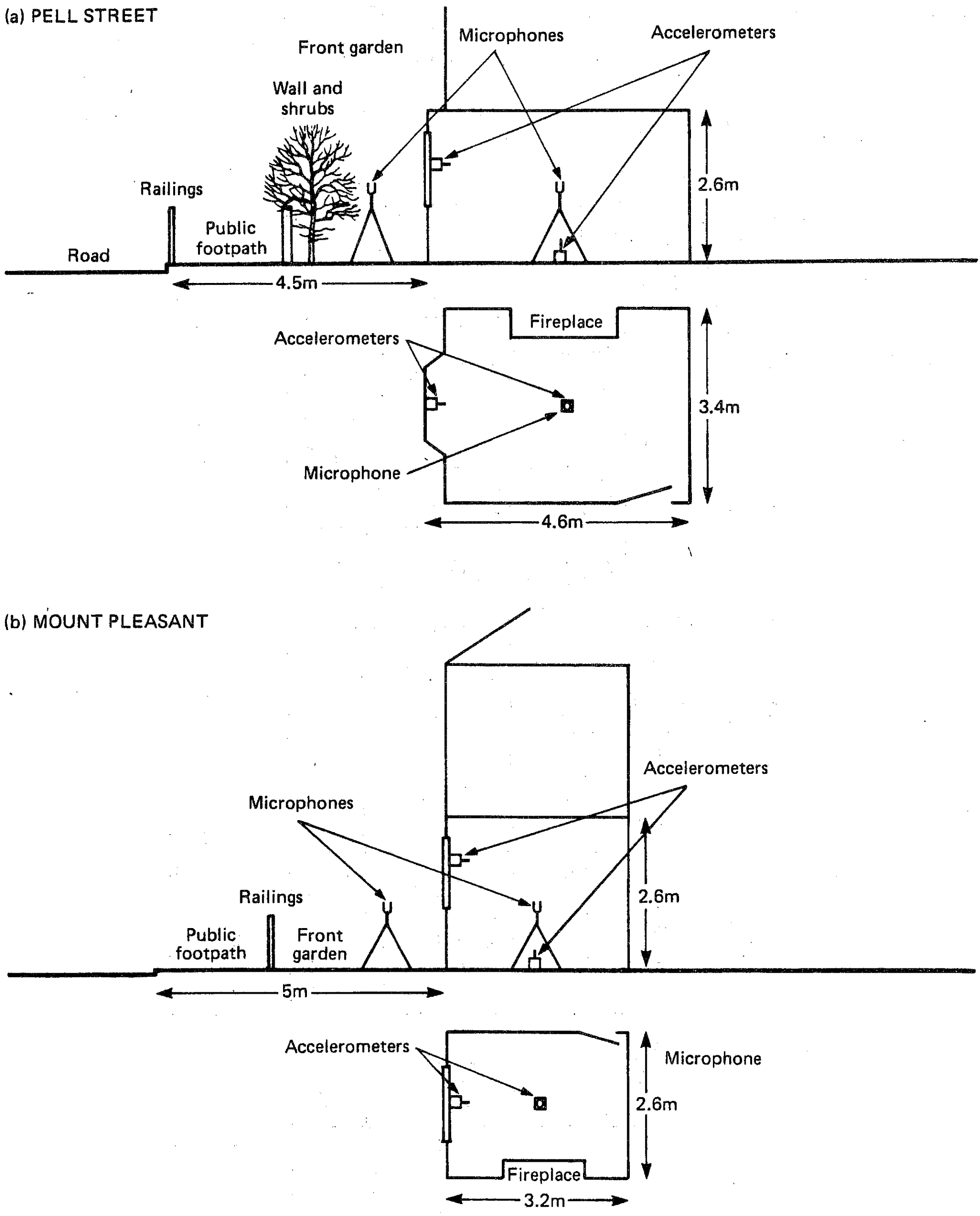

Fig.1 Measurement locations at test houses

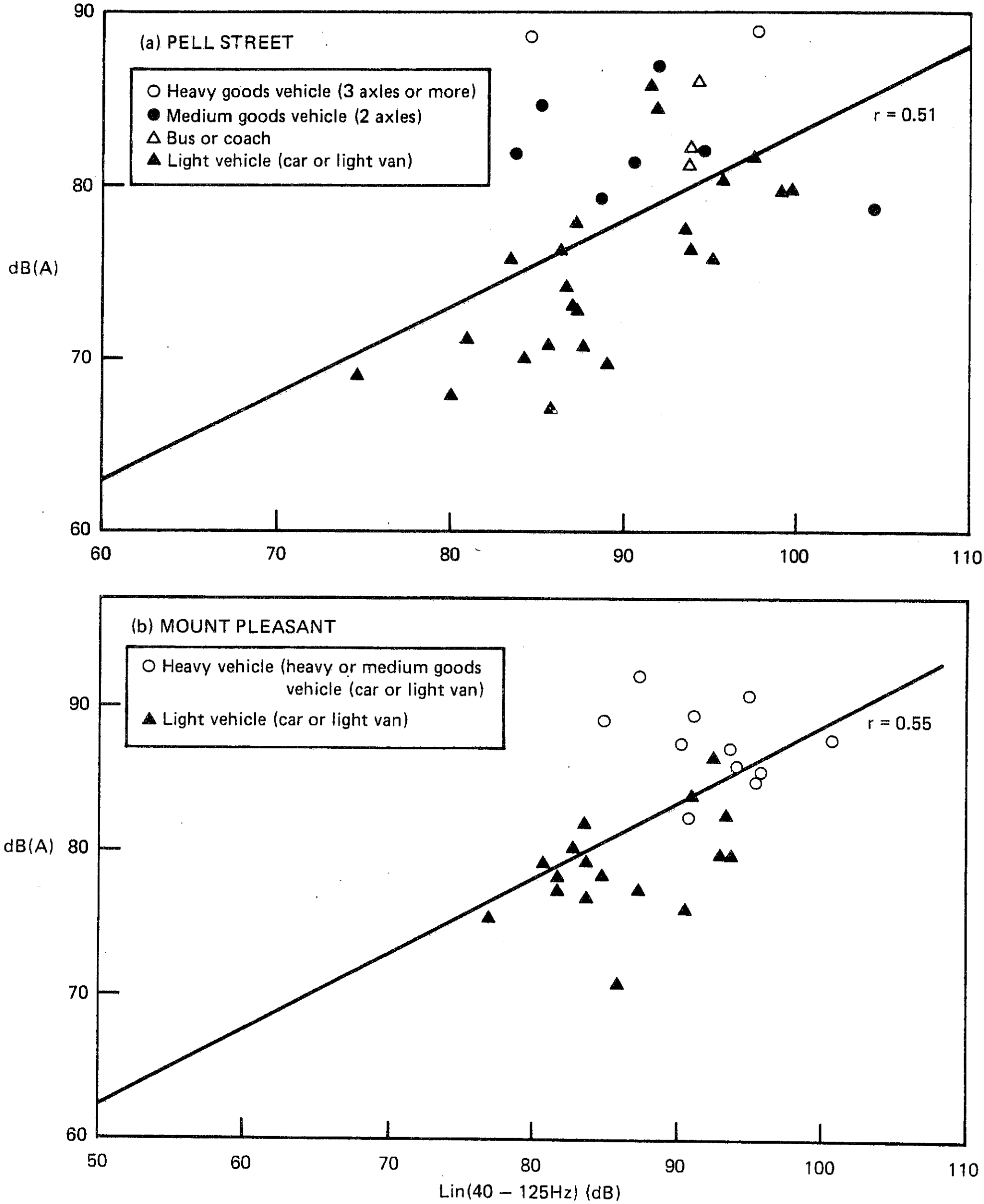

Fig.2 Maximum A-weighted and low frequency noise levels at the facades for vehicles passing on the nearside at a steady speed