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TRAFFIC-INDUCED GROUND-BORNE VIBRATIONS IN DWELLINGS

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INTRODUCTION

A previous survey carried out at 50 sites involving over 1600 residents examined the problem of the nuisance caused by traffic induced vibrations in dwellings [1]. The study aimed to determine physical measures which would correlate well with annoyance due to vibration as measured by means of a questionnaire rating scale. It was found that noise exposure measures taken at the facade were reasonably well correlated to this nuisance. This was expected since it is known that low frequency noise is largely responsible for commonly experienced vibration effects in dwellings [2,3]. However it was considered that some of the disturbance might result from the effects of ground-borne vibration and this paper describes a study designed to address this problem.

It is known that vehicles travelling over surface irregularities can in certain circumstances produce large dynamic forces at the tyre/road surface interface which in turn produce significant body and surface waves in the surrounding soil. Theoretical analysis has shown that in circumstances such as this, most of the vibration energy appears in the Rayleigh surface wave and that the principal component of vibration is in the vertical direction. The most likely manifestation of this type of vibration was therefore thought to be the movement of floors, especially those of a suspended wooden construction. If these vibrations were above or near the threshold of perception then this could lead to disturbance in addition to any annoyance due to acoustic excitation and may result in a higher than expected rating.

MEASUREMENT OF VIBRATION

All the 50 groups of houses were visited and the adjacent road surface inspected for features likely to produce relatively large ground-borne vibrations. There were 12 locations where vibrations were clearly perceptible at the kerbside next to an irregularity in the road surface and where it was considered that ground-borne vibrations might be perceptible in dwellings in close proximity. Sensitive accelerometers (10V/g) were used to record vertical vibrations at the kerb next to the irregularity, on the ground close to the facade of a house nearby and in the middle of the ground floor room fronting the road. A microphone was placed 1m from the facade at a height of 1.2m. The signals from the accelerometers and microphone were conditioned using measuring amplifiers which also provide the required dc voltage for the pre-amplifiers in the bases of the accelerometers. A Racal Store 7DS instrumentation recorder was used to record the signals which at a speed of 7½ in/s gave a level frequency response from dc to 4000 hz. The approximate position of the nearside wheel track for heavy vehicles was marked. In all cases it was considered that the profile of the irregularity along the nearside wheel track rather than the off-side track was more severe so that the largest vibrations were likely to have been generated close to the marker strips. Over a few hours the vibrations produced by passing vehicles were recorded and the vehicle speeds were measured using a radar speed meter.

The descriptions of the vehicles and their approximate positions relative to the marker were also noted. The disturbing effects of the various irregularities at the different locations were compared by generating a standard input. For this purpose a 2-axle flat bed lorry loaded with concrete blocks to near the maximum permissible load per axle was driven past the sites and over the marker strips at various speeds in the range from approximately 15 to 50 kph.

The longitudinal road profiles at the tape marks were measured using a laser plane. This device consists of a portable battery operated laser source and an electronic surveyor's rod. Height measurements were made to the nearest mm, generally at 100mm intervals along the road.

ANALYSIS

Third octave analysis was employed to determine whether or not levels of vibration in dwellings close to individual irregularities were perceptible and to attempt to relate the characteristics of the profile to the likely degree of nuisance produced. Finally, time domain and narrow band analyses were used to verify the importance of ground-borne vibration at the measurement sites and to determine whether or not proposed building damage thresholds were being approached or exceeded.

Third octave analysis

A digital third octave real time analyser was used to capture the maximum vibration and noise levels in each frequency band during the play-back of individual pass-by events. At each site the third octave levels for each vibration event was compared with the perception threshold for vertical (foot to head) vibration given as the z-axis base curve in BS 6472 [4]. Plots of vibration and noise spectra were made for the most significant events.

Time record and narrow band analyses. The most significant vibration events at each site were examined further using a dual channel digital signal analyser. An examination of the variation of acceleration with time was used to determine the maximum acceleration for each event. Using a 2.5s time window the analyser enabled the linear spectrum from dc to 100Hz to be calculated. The width of each narrow band was 0.39Hz.

RESULTS

Degree of disturbance

In order to obtain an indication of the degree of disturbance at the houses where vibrations were recorded and to gauge the relative importance of ground-borne and acoustically coupled vibration in causing perceptible floor vibration the numbers of events in which vibration exceeded the perception threshold in the frequency bands 5-25Hz and 50-80Hz was obtained. Ground-borne vibration contributes most of the vibration energy in the 5-25Hz band and acoustically coupled vibrations are generally predominant in the 50-80Hz ⅓ octave bands. Table 1 lists the number of perceptible events for those locations where there were more than just a very small number of perceptible events in the measurement period. Based on traffic flow data collected during the 50 site survey an estimate was made of the number of such events over an 18 hour period. Using the occupiers responses obtained during the 50 site survey the median vibration nuisance rating for respondents likely to have been exposed to perceptible ground-borne vibrations were compared with the overall site median rating. Only along one road (where measurements were made at 3 locations A,

Table 1. Occurrence rates of perceptible floor vibrations

Measurement site	Vehicle type#	Number of events analysed	Number of possible events			Estimated number of perceptible vibrations produced by MGVs and HGVs	
			Number in 5-25 Hz band	Number in 50-80 Hz band	Number in 5-80 Hz band*		
A	Light	4	2	-	2		
	MGV	[illegible]	12	2	12	184	308
	HGV	23	18	4	18	124	
B	Light	6	1	-	1		
	MGV	23	16	11	21	322	[illegible]
	HGV	9	6	6	9	156	
C	Light	10	-	-	-		
	MGV	46	9	-	9	69	107
	HGV	21	13	1	13	[illegible]	
D	Light	7	-	-	-		
	MGV	38	6	-	6	86	107
	HGV	19	4	-	4	21	
E	Light	8	-	-	-		
	MGV	35	12	-	12		
	HGV	1	-	-	-	158	158

Vehicle classification

Light: cars and small vans

MGV: two-axled goods vehicles and buses and coaches

HGV: goods vehicles with three or more axles.

* Some events exceed perception threshold in both 5-25 and 50-80 Hz bands.

B and C) was the median rating for residents affected by ground-borne vibration greater than the overall rating for that site. Because of the small sample size this was not statistically significant.

Effects of vehicle size and speed. At location (C) all the perceptible vibrations (except one) which resulted from vehicles passing over one of the marked profiles exceeded the threshold in the 12.5Hz third octave band and so comparisons of the disturbing potential of various vehicles by speed can be readily made. Figure 1 shows a plot of the maximum rms acceleration in this third octave band against speed for the three classes of vehicle (light vehicles and medium and heavy goods vehicles). In the case of the heavy goods vehicles there is a trend of increasing maximum level with increasing speed. The plot shows that the majority of vehicles exceeding the perception threshold (8mm/s^2 at this frequency) were heavy goods vehicles. This is in contrast to acoustically induced vibration where there was found to be more of an overlap in the effects of different vehicle types [5].

Effects of the size of the irregularity. In order to compare the disturbing effects (ie. the amount by which the perception threshold is exceeded) of the vibrations due to various irregularities a standard set of conditions was assumed. The input was the test vehicle travelling at 40kph over the section of road where the profile was measured and an average attenuation rate was assumed. The latter was calculated from the data at all sites. The disturbing effect at a distance of 5m from the profile was calculated. This is a typical distance for the separation between near-side wheel track and the facades of turn-of-the-century terraced properties fronting main roads. The expected level in each ⅓ octave band at exactly 40kph was computed by determining the relationship between recorded level and speed at each site. For a particular site the calculated ⅓ octave levels were compared with the perception threshold curve. The maximum ⅓ octave level with respect to the threshold at the frequency (a measure of the disturbing potential of an irregularity) was plotted against the maximum depth or height of the irregularity (Figure 2). The zero point on the vibration scale indicates the threshold of perception. Apart from one point (which refers to a joint in a concrete road) the data lie close to a straight line. The height or depth of an irregularity which just gives rise to perceptible vibrations at 5m is 22mm.

Potential for building damage. The peak acceleration levels for the largest vibration events at the facade and on the floor were determined from the relevant time records and the dominant frequences were obtained from the linear spectra. This enabled calculation of thevibrar level, which is a measure of the damage potential of a vibration event. On the Zeller scale [6] the suggested threshold for cracking of plaster corresponds to a vibrar level of 27.

Table 2. Peak acceleration and vibrar level by location

Location	Position	Peak acceleration level (mms^{-2})	Dominant frequency (Hz)	Vibrar level*
A	Facade	75	12	16.7
	Floor	175	12/74	24.9/16.2
B	Facade	130	12.7	21.2
	Floor	164	12.5	23.3
C	Facade	110	13	19.7
	Floor	114	12.5	20.2
D	Facade	42	60	4.7
	Floor	78	25.5	13.8
E	Facade	57	10	15.1
	Floor	96	24	15.8

*The vibrar level is given by $10 \log \left(\frac{a^2}{10f} \right)$ where 'a' is the peak acceleration and 'f' is the frequency.

Other damage thresholds have been proposed in various countries [6,7] and this represents one of the lowest thresholds. No event was recorded which exceeded the Zeller threshold for even minor damage. It is not known whether the repetition of vibration events which are below threshold might over a long period of time produce damage by some cumulative action (eg. fatigue or soil settlement). In addition, a relatively low level vibration may 'trigger' damage in a building under stress for other reasons. Further research is needed to relate vibration levels typical of traffic induced vibrations to quantifiable damage in buildings.

CONCLUSIONS

Vibration measurements have been taken at a number of houses where preliminary investigations indicated that ground-borne vibrations were likely to be perceptible on floors. The houses were a small part of a sample of over 1600 that were included in an earlier survey of vibration nuisance at 50 residential sites. Perceptible ground-borne vibrations were recorded on the living room floor of 5 of these houses and calculations show that it is likely that a small number of additional houses would be exposed to this level of vibration. Because of the limited amount of data for residents affected by these vibrations it was not possible to determine whether or not these vibrations contributed significantly to vibration annoyance ratings. All these affected houses were close to road surface irregularities. Heavy goods vehicles and buses tended to produce the most perceptible vibrations inside the houses studied. For such vehicles vibration levels tended to increase with vehicle speed. Vibration levels also increased with the maximum height or depth of the road surface irregularity. The data suggest that where a building is within 5m of an irregularity with a height or depth greater than approximately 20mm there exists the possibility of perceptible ground-borne vibrations being generated on suspended wooden floors during the passage of heavy vehicles. The length and detailed shape of the surface irregularity was not found to be important. A joint in a concrete road surface gave results markedly different from other road surface features. At none of the measurement sites did the peak vibration level near the facade or on the ground floor exceed one of the lowest thresholds for minor damage that has been proposed for this type of building.

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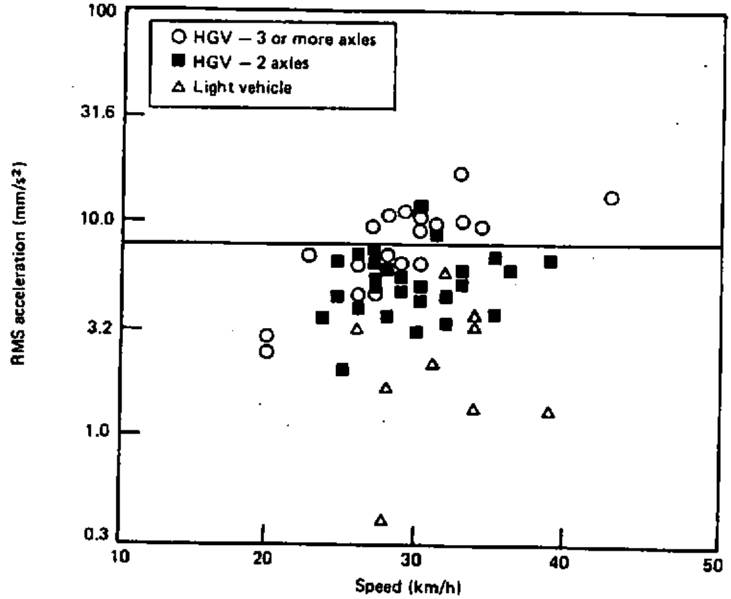

Fig. 1 Maximum 12.5Hz third octave levels on the floor at location C produced by various vehicles

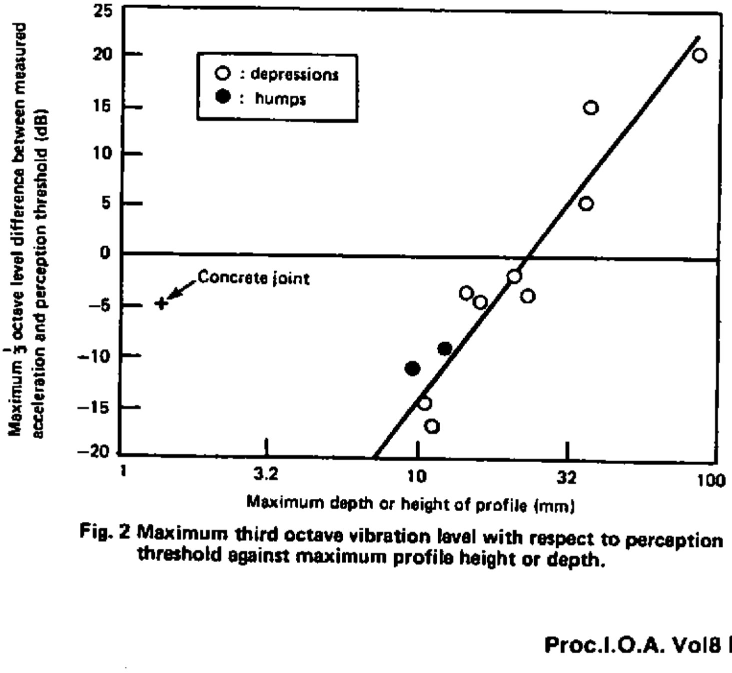

Fig. 2 Maximum third octave vibration level with respect to perception threshold against maximum profile height or depth.