Proceedings of The Institute of Acoustics

RESPONSE OF BUILDING ELEMENTS TO SIMULATED TRAFFIC VIBRATIONS

G.R. Watts

Transport and Road Research Laboratory, Crowthorne, Berkshire

INTRODUCTION

An unoccupied dwelling was subjected to simulated groundborne and airborne vibrations as part of a programme of research into quantifying the effects of traffic induced vibrations on buildings. This paper describes the response of the structure to this exposure in terms of peak particle velocity and crack movements.

The building consisted of a pair of semidetached houses approximately 80 years old built on medium to loose sand. The groundborne vibrations were produced by a geophysical vibrator located approximately 2 m from the side wall at the right hand side of the building. Levels were adjusted so that the peak vertical velocity at foundation level was in the range 2.5-3.0 mm/s. This is at the extreme end of the range of peak velocities measured in buildings close to large roadside irregularities during the passage of heavy vehicles [1]. The driving frequency was adjusted to approximately 13 Hz which is within the range found in practice and produced a relatively large response in the structure. Figure 1(a) and (b) show the time history and frequency content of a typical pulse. The house was exposed to 880,000 pulses simulating the effect of over 3.5 million goods vehicle axles.

Airborne vibrations were produced by four Celestion speakers mounted in the sides of a lorry parked close to the left hand side of the front facade. The speakers were driven by a 500 W amplifier and the signal was generated by a CED computer. A broad range of frequencies were first produced in order to simulate general traffic noise but it was found that the various building elements vibrated at a very low level. Tests showed that resonances in the ground floor window and floor could be excited by a narrow range of frequencies centred in the 25 Hz third octave band (figure 2). The peak level was adjusted to approximately 110 dB producing an exposure which was considered to have a damage potential at least as large as that produced by heavy goods vehicles passing close to the facade under the worst operating conditions. The pulse length selected was 2 seconds and the passage of approximately 500,000 such vehicles was simulated.

INSTRUMENTATION AND ANALYSIS

Measurements of particle velocity were made in three orthogonal directions using long travel geophones (sensitivity 27 mV/mm/s). These were attached using either Plaster of Paris or steel angle brackets. The signals were conditioned using a bank of operational amplifiers the input impedance of which was adjusted to give a level frequency response in the range of interest ie 5-100 Hz. The signals were recorded on a FM tape recorder and time and frequency domain analyses were carried out using a Hewlett Packard digital signal analyser, computer and plotter. Time domain analysis allowed the particle velocities in three directions and the corresponding resultant to be plotted and maximum values computed. Cross correlation of signals from separated geophone arrays was employed to determine the progation velocity of both compression and shear waves. Linear fourier transforms were computed at a resolution of 0.39 Hz and used to establish the principal frequency components and associated harmonics. Sound recordings were made with a ½ inch microphone and third octave analysis was carried out using a Bruel and Kjaer digital third octave analyser. Crack movements were measured using a TML strain gauge which allowed movements of 1 micron to be resolved.

RESPONSE TO GROUNDBORNE VIBRATIONS

Investigations showed that the response of the building to groundborne vibrations was complex. This was partly due to the fact that the building was not subject to plane waves since the vibrator was positioned only 2 m from the side wall. In addition the forcing frequency was not purely sinusoidal since it included a number of significant harmonics (see figure 1(b)). As expected it was found that suspended wooden floors and ceilings were among the building elements showing the greatest response. Triaxial measurements were made in the middle of floors, on roof joists and on the floor of the cellar. Figures 3(a) and (b) show the variation of vibration level between the various measurement positions. There is a clear trend of increasing level with height for both vertical and radial components which is likely to be due to the decreasing dead load and restraining influence of the ground and changes in the mass and stiffness of the suspended floors. Although vertical levels decay rapidly with horizontal distance, radial and transverse components do not. It appears that vertical shear waves are more greatly influenced by the damping in the underlying soil. Levels on the external brickwork of the front facade followed broadly similar trends although absolute levels differ.

The highest levels were recorded in the first floor room adjacent to the vibrator where the most obvious damage to the building occurred. This was limited to a number of hairline cracks in the lath and plaster walls and ceiling and a small piece of loose plastic was dislodged. No structural damage had occurred. Figure 4 shows a plan of this room which is labelled A in figure 3(a). Numbers 1 to 9 and labels a to f refer to geophone and strain gauge monitoring positions respectively. Tables 1 and 2 list the peak velocities and crack movements that were recorded. It can be seen from table 1 that the highest levels occurred on the window pane and in the middle of the ceiling.

Table 1. Peak vibration levels due to vibrator

Measurement position	Axis of measurement	Peak velocity (mm/s)
1. Middle of wall	Transverse	2.85
2. Middle of wall	Radial	7.17
3. Middle of wall	Transverse	6.46
4. Lower pane in window	Transverse	41.53
5. Middle of chimney breast	Radial	3.10
6. Middle of ceiling	Vertical	19.37

The vibration level on the chimney breast (position 5) was substantially less than on the opposite wall (position 2) and this was probably due to the high mass and stiffness of this structure. These vibrations were in phase and because of the difference of velocity (4.1 mm/s) a maximum displacement of 50 microns was expected across the ceiling on each cycle. Strain gauge measurements showed that virtually all this movement was accommodated at two cracks (d and f) one of which had developed during exposure (see table 2). These were the highest measured crack movements in the building.

Table 2. Peak crack movements

Measurement position	New/old crack	Axis of measurement	Peak displacement (μm)
a. Near middle of wall	New	Vertical	4.0
b. Wall near floor	Old	Transverse	9.1
c. Wall close to ceiling	Old	Vertical	16.4
d. Ceiling	New	Radial	28.4
e. Wall close to ceiling	Old	Vertical	16.3
f. Ceiling	Old	Radial	28.4

RESPONSE TO AIRBORNE VIBRATION

Table 3 lists the peak levels of vibration in rooms most affected by the airborne vibrations (see figure 5).

Table 3. Peak vibration levels due to noise source

Measurement position		Axis of measurement	Peak velocity (mm/s) Ground floor room	First floor room
1.	Lower pane in window	Radial	130.90	-
2.	External wall near foundations	Radial	0.11	-
3.	External wall 1.8 m high	Radial	0.87	-
4,5.	Middle of wall	Radial	1.93	0.90
6,7.	Middle of side wall	Transverse	0.52	0.82
8,9.	Middle of floor	Vertical	0.17	2.46
10.	Middle of chimney breast	Transverse	0.18	-

The linear sound pressure levels measured at a height of 1.2 m above the middle of the ground and first floor rooms were 98.6 and 89.5 dB respectively. The ground floor responded poorly due to the restraining influence of brick sleeper walls under the joists. The peak level on the suspended floor above was nearly 2.5 mm/s due to the fact that its natural frequency was close to the driving frequency. The highest level of over 130 mm/s was produced on a ground floor window pane. This was expected since the source was adjusted to obtain resonance. Comparing levels at points 3 and 4 on opposite sides of a wall it can be seen that the lath and plaster responded more to airborne vibration than the much stiffer brickwork. Vibration levels produced by the acoustic source in other rooms were barely perceptible unlike the levels produced by the vibrator. For example the level on the chimney breast in the adjacent room was only 0.18 mm/s.

RESPONSE TO DOMESTIC ACTIVITY AND TRAFFIC

Household activities such as heavy footfalls and slamming doors can produce very large vibrations especially on the floors and ceilings close to the source. To determine the extent to which this vibration reaches the external brickwork triaxial geophone arrays were placed 4 m above the ground and at foundation level (positions 8 and 9 in figure 4). Vertical impulses to the floors were generated by jumping from a stool placed in the middle of the ground and first floor rooms. Horizontal impulses were provided by slamming the bedroom door on the first floor and the door to the side entrance on the ground floor.

Table 4. Peak resultant vibration levels resulting from activities

Activity	Location	Peak velocity (mm/s) Foundations (position 9 in figure 4)	Peak velocity (mm/s) 4m above ground level (position 8 in figure 4)
Jumping from stool	Position 6 in first floor room	1.26	3.64
	Position 7 in ground floor room	0.35	0.72
Slamming door	In first floor room	1.04	5.68
	Outside door in ground floor room	3.12	7.04

From table 4 it can be seen that the largest resultant levels were produced by slamming doors and that the levels recorded at 4 m were always greater than at foundation level. It was expected that a vertical impulse on the ground floor would have relatively little effect because of the presence of sleeper walls under the joists.

To gauge the effects of traffic, a two axle lorry laden close to the maximum permissible axle loads was driven past the site at various speeds. At the highest speed achievable perceptible vibrations were generated as the vehicle crossed a sunken manhole cover 27 m from the measurement point. The peak resultant vibration was 0.32 mm/s at the foundations (position 9). On the first floor the highest level recorded (1.18 mm/s) was near the point closest to the irregularity (position 3). The highest recorded level at the foundations produced by general traffic was 0.66 mm/s.

CONCLUSIONS

The whole building responded relatively strongly to simulated groundborne traffic vibrations and vibration levels in the suspended wooden floors and ceilings on the first floor adjacent to the vibrator were among the highest recorded. Although these vibrations were very noticeable, and would be unacceptable to most occupants, crack movements were relatively small, the largest peak displacement being only 28 microns. It should be noted that changes in temperature and moisture content in walls and ceilings are known to produce movements much greater than this [2,3]. Acoustically induced vibrations were only perceptible in rooms close to the noise source and levels were generally below those produced by the vibrator despite the extreme nature of this simulation. Domestic activity such as slamming doors produced peak vibration levels in the hard structure of the building comparable to those produced by the groundborne vibrations. Vehicles passing the site produced relatively small but measureable vibrations, greater response being noted on the first floor.

ACKNOWLEDGEMENTS

The study formed part of the programme of research of the Vehicles and Environment Division of TRRL. The assistance of Mr Godfrey is gratefully acknowledged. The test house and vibration sources were prepared by Travers Morgan Planning under contract to TRRL.

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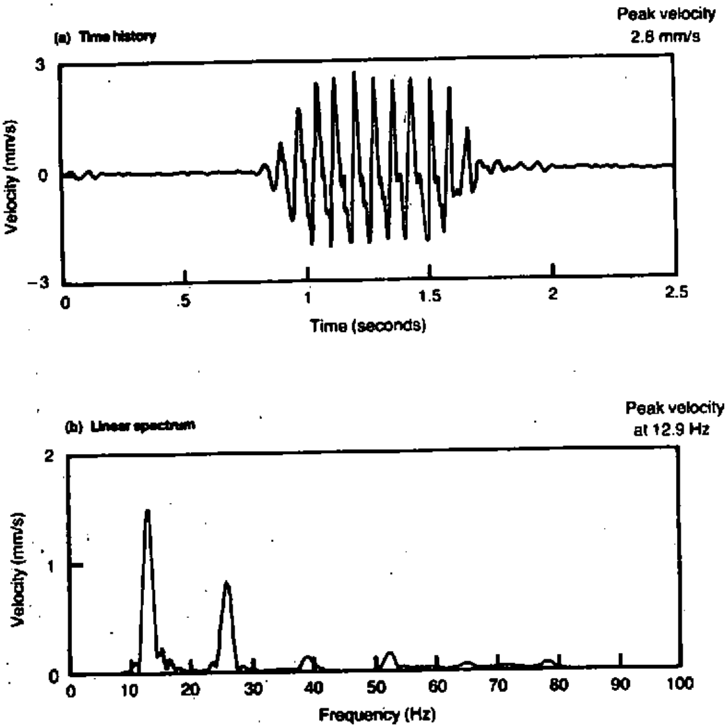

Fig. 1. Vertical particle velocity at foundations adjacent to vibrator

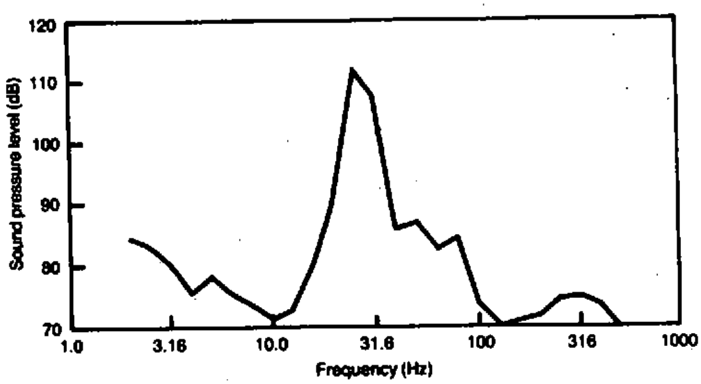

Fig. 2. Third octave sound levels in gap between speaker array and facade

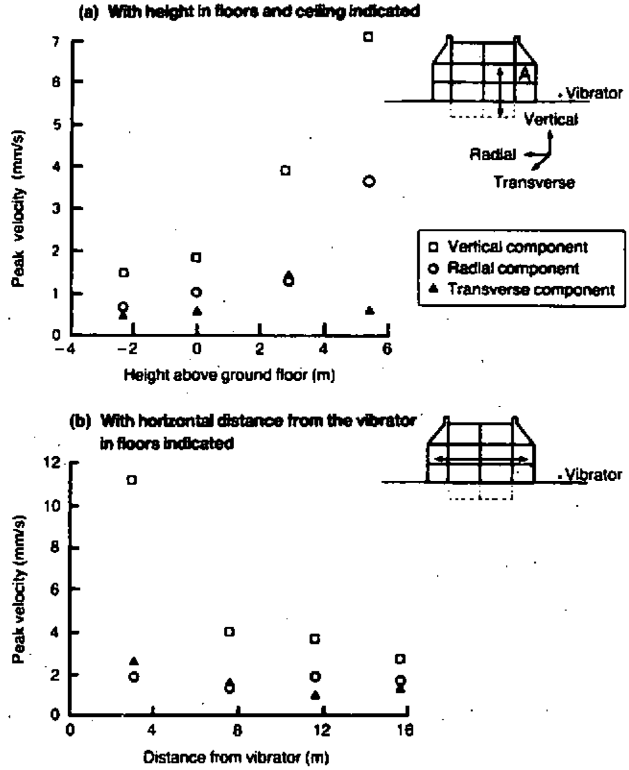

Fig. 3. Variation of peak particle velocity on floors and ceiling joists

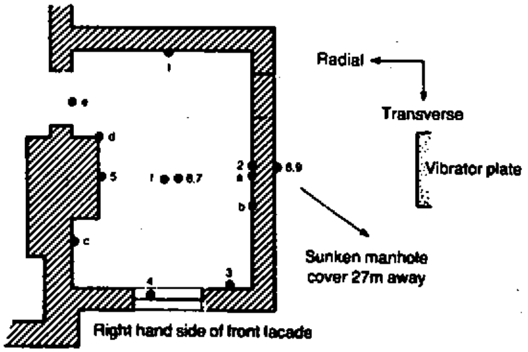

Fig. 4. Location plan of first floor room near vibrator

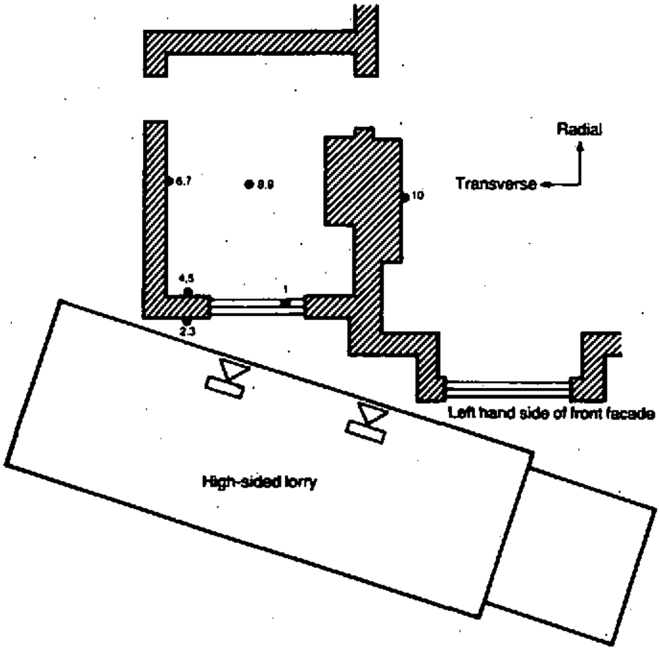

Fig. 5. Location plan of ground floor near noise source