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TRAFFIC INDUCED VIBRATIONS IN BUILDINGS

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1. INTRODUCTION

A series of studies have been carried out at the Transport Research Laboratory (TRL) to understand the scale and nature of the problems caused by traffic-induced vibration in buildings and then to develop methods of predicting disturbance and reducing the effects.

The scale of the problem experienced by residents was indicated in a broadly based survey of environmental disturbances caused by road traffic [1]. It was found that 37% of residents experienced traffic vibration and 8% were seriously bothered by the effects. Traffic vibration, therefore, represents an environmental disturbance affecting large numbers of people.

This paper reviews the most important aspects of the work and summarises the main conclusions. In the first part a description is given of the nature of the disturbance as revealed by surveys and the methods which have been developed to predict the degree of disturbance from physical measures. The results should prove useful in assessing the environmental impact of traffic management schemes or the construction of new roads. The second part of the paper addresses the important issue of whether damage to buildings can be caused by traffic vibration.

2. TYPES OF TRAFFIC VIBRATION

Passing vehicles can induce vibrations in buildings in two major ways. Low frequency sound produced by large vehicle engines and exhausts has dominant frequencies in the 50-100Hz range corresponding to the fundamental firing frequency. These frequencies readily excite window panes causing annoying rattles and sometimes can produce perceptible floor vibrations. Ground-borne vibration has dominant frequencies in a lower frequency band, typically

8-20 Hz. These vibrations are produced by the varying forces generated between tyre and road and can become perceptible in buildings if heavy vehicles pass over irregularities in the road near the properties. Both compression and shear waves are produced and their amplitudes and attenuation with distance depend on a number of factors including the soil composition and the nature of the geological strata. Since this vibration enters buildings through the foundations, the hard structure of the building is normally affected to a greater degree than is the case for airborne vibration. Often these vibrations are most noticeable when standing or sitting near the middle of suspended wooden floors.

3. VIBRATION NUISANCE

In order to gauge the size and nature of the problem of nuisance caused by vibration the TRL carried out a questionnaire survey at 50 residential sites in England [2]. At one house per site external noise and window vibration were recorded for 15 minutes every hour over 24 hours. In addition at the small number of sites where ground-borne vibration was likely to be perceptible recordings were taken near ground level at the front facade and in the middle of the ground floor.

3.1 Results from the survey

Results were obtained from over 1600 completed interviews. Table 1 lists the percentage of respondents who noticed various traffic-induced vibrations in their homes. A large percentage (62%) noticed windows or doors rattling or buzzing and 30% had noticed that the floor shook or trembled.

Table 1: Percentage of respondents who noticed various vibrations

Vibration effect	Percentage noticing effect
Windows or doors rattling or buzzing	62.2
Floors shaking or trembling	29.5
Ornaments rattling or buzzing	15.7
Traffic causing the bed to shake	13.6
Muffled sensation in the ears or fluttering sensation in the chest	18.9
Feeling vibration in the air	30.2

Table 2 shows that an important reason given for respondents being bothered by vibration was the possibility that traffic vibration could damage their homes (55%). It also indicates that the perception of traffic vibration also heightens people's awareness of the traffic.

Table 2: Percentage of respondents bothered by vibration for various reasons

Reason	Percentage bothered
It has damaged this house/flat	19.6
It could damage this house/flat	54.7
It interferes with sleep	35.9
It makes you jump, or frightens you	27.0
It gets on your nerves	44.6
It feels unpleasant	41.7
It reminds you of the traffic	55.9
It interferes with the TV picture	27.3

Table 3 lists the percentage of residents who reported actual damage of various kinds. Fewer people reported serious structural damage (cracks in brickwork or damaged foundations) than architectural defects such as cracks in plaster finishes.

Table 3: Percentage of respondents reporting damage thought to be caused by road traffic

Damage reported	Percentage reporting damage
Roof tiles falling or moving	31.6
Cracks in plaster on walls or ceilings	25.8
Cracks in brickwork	10.0
Cracked windows	19.9
Subsidence	13.7
Damaged foundations	7.6

3.2 Assessment of airborne vibration nuisance

Based on this survey the percentage of residents bothered by vibration at various levels of noise exposure could be calculated. It can be seen in Figure 1 that at high levels of noise level exposure ie $L_{A10,18h} > 75$dB over 50 % are bothered "very much " or "quite a lot" by vibration. The large fluctuations at low noise exposure levels is probably due to sampling error since only a small number of sites was used to compute the percentage bothered. A sigmoid curve was fitted to these data and allows predictions of the level of nuisance for a given level of noise exposure.

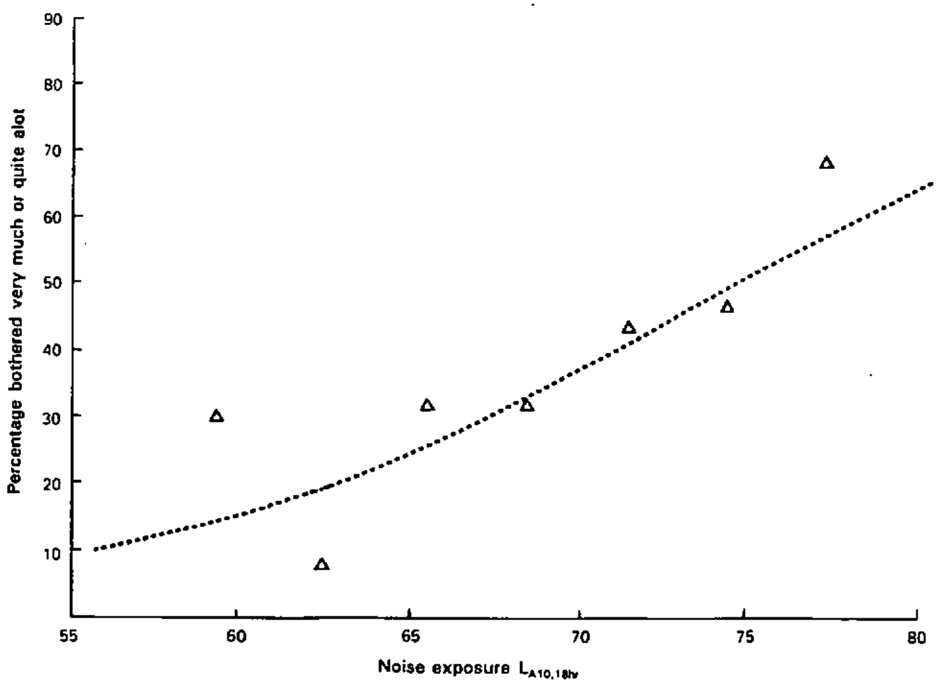

Figure 1: Percentage of respondents bothered by vibration by noise exposure level

3.3 Assessment of ground-borne vibration nuisance

Although ground-borne vibration problems are not nearly as widespread as those produced by airborne vibration, maximum amplitudes can reach relatively high levels, well above the level of perception in unfavourable circumstances, and could cause anxieties about property damage. Vigorous complaints might therefore be expected under the worst combination conditions. A prediction practical prediction method has been developed at TRL which enables peak vertical vibration at the foundations of buildings to be determined. Track tests with a wide range of HGVs established the trends in peak vibration levels with vehicle speed, load and size of irregularity. These results were then generalised to different site conditions by determining the amplitudes and attenuation rates in various soils using a falling weight impact method [3]. By determining the average effects of these factors it was possible to estimate the likely range of the maximum amplitude (or peak) of vertical particle velocity (PPV) at the foundations of buildings for a variety of site conditions [4]. It was found that peak levels of vibration can be as high as 10 times the level of perception threshold and that the highest levels occurred on soft soils such as peat and alluvial deposits. A full description of the prediction method is given in reference [4].

On the available evidence it is not possible to give precise guidance on the minimum vibration measured at building foundations above which complaints from occupants can be expected. However, these studies indicate that if levels are significantly above 0.3mm/s then some degree of disturbance will probably occur while if levels are well in excess of 1.0mm/s then this may prove unacceptable and complaints may be made.

4. VIBRATION DAMAGE

The vibration survey has indicated that there is a widespread belief that traffic vibration can cause building damage. In addition the Civic Trust, consulting engineers and academics who are involved in the preservation of historic buildings and monuments have expressed concern at the effects of traffic vibration on these sensitive buildings [5,6,7,8]. Despite these anxieties there was little evidence to support or reject these beliefs and it was necessary to study the problem using a variety of techniques and involving a wide range of buildings and soil types so generalizations could be made with some degree of confidence.

4.1 Possible damage mechanisms

There are four mechanisms hat may result in vibration damage in buildings.

(i) direct failure - if vibration levels are high enough the stresses imposed can cause direct failure.

(ii) trigger damage - although peak levels of vibration induced by traffic are well below those that have been proved to cause direct damage it is not inconceivable that a small additional stress imposed by traffic vibration might possibly add to a much greater static stress resulting in damage.

(iii) fatigue damage - long periods of exposure to low levels of vibration may produce fatigue damage in building components.

(iv) vibration assisted settlement - it is known that soils such as loose sand can be induced to reduce volume if subjected to vibration so the possibility exists that buildings on such soils may settle causing serious structural damage.

4.2 TRL studies

It was decided at the outset the research methods adopted must be capable of separating damage caused by traffic vibration from the effects of natural ageing and weathering and settlement that might be expected on loose or soft soils. Three types of study were identified which satisfied this basic objective and are described briefly below.

4.2.1 Fatigue study. This study involved the exposure of a conventional two storey building built on loosely compacted sandy soil to high levels of simulated traffic vibration. The intention was to produce in a few months the equivalent of many years of exposure to heavy traffic. Ground-borne vibration was simulated using a geophysical vibrator located 2m from a side wall of the building and airborne vibration was simulated using four large loudspeakers mounted in the wall of a high sided lorry (see Figure 2).

Throughout the exposure period the building was carefully monitored to determine the extent to which cracking and subsidence occurred. Electrolevels and extensometers were employed to measure soil movements and levelling stations were installed at 36 locations on the structure to determine any foundation settlement. Forty existing cracks in various locations were monitored for movement during the period of exposure to simulated traffic vibration.

The results showed that there was no detectable settlement of the house. No structural or trigger damage was found but fatigue damage occurred in the end wall of the house facing the vibrator and in the ceilings close to the chimneys. However the amount of damage was very slight and probably would have gone unnoticed in a normally decorated house. Of the 40 cracks which were monitored, only five showed significant changes in crack width of 0.1mm or more during the exposure period. Further details of this study are given in reference [4].

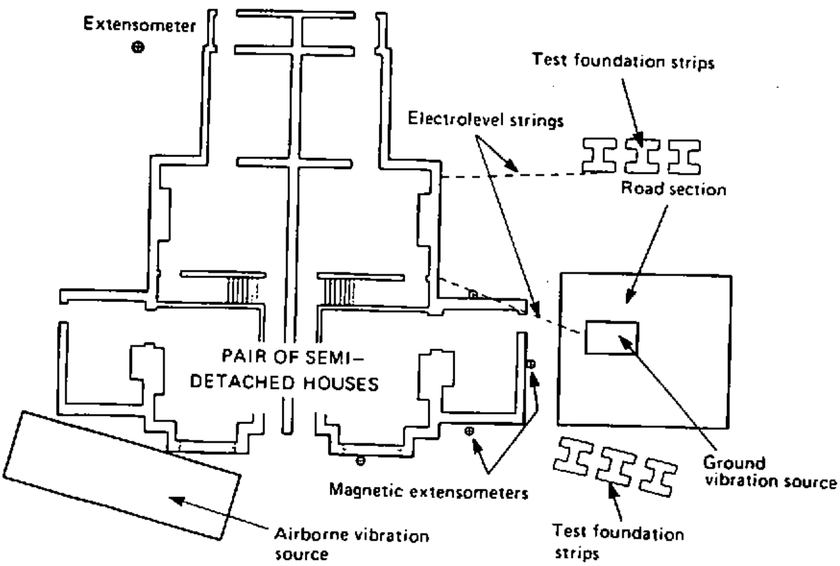

Figure 2: Site layout for fatigue test of a pair of semi-detached houses

4.2.2 Pairwise comparisons. The objective of this study was to determine if excess damage occurs in occupied houses which have been exposed to relatively high levels of traffic vibration over a considerable period of time when compared with similar houses that have not been exposed to significant vibration. Worst case sites were sought so that the effects of these vibrations might more readily be detected. Since differential settlement did not occur on sands in the fatigue test described above, it was considered worthwhile to investigate the possibility of this effect occurring in soft ground such as saturated alluvial deposits. Therefore rows of houses were sought in areas where there were known to be generally soft soils. Sites were found in King's Lynn, Bridgwater and Cardiff and at each site similar rows of houses built on comparable soils but exposed to very different levels of vibration were identified. Vibration measurements were made at the foundations of the properties fronting the heavily trafficked roads and also at the control sites. The results established that vibration levels were very much greater at the exposed sites than at the control sites. At each site the level of perception (0.3mm/s) at was exceeded at the foundations of the buildings exposed to traffic vibration (see Table 4).

Table 4: Peak particle velocities at paired comparison sites

Site		Peak vertical velocity (mm/s)	L_{10}* linear level (dB)
King's Lynn	Saddlebow Road (exposed)	0.96	87.5
	Beloe Crescent (control)	<0.10	83.5
Bridgwater	Bristol Road (exposed)	1.16	89.5
	Devonshire Street (control)	<0.08	77.6
Cardiff	Penarth Road (exposed)	0.42	89.0
	Chester Place (control)	0.25	82.0

* L_{10} linear level is the unweighted level which is exceeded for 10 per cent of the recording period.

The comparison of building damage in exposed and control properties was a difficult task requiring skilled professional judgement. In many cases it proved impossible to obtain permission to carry out internal inspections and so the survey relied heavily on the comparison of external defects. Table 5 shows the number of houses inspected at exposed and control sites at each of the three sites.

Results showed that at all sites there were no significant differences in the amount of damage in exposed and control properties. It is possible that some minor damage effects may not have been found because of the problems of identifying this level of damage in normally decorated and occupied homes.

Table 5: Number of houses inspected at exposed and control rows

Site	Exposed row			Control row		
	External and internal	External only	Total	External and internal	External only	Total
King's Lynn	6	–	6	3	–	3
Bridgwater	6	15	21	1	12	13
Cardiff	3	7	10	4	7	11

4.2.3 Heritage building surveys. In order to assess the possible contribution of traffic vibration to damage in older properties, eight buildings ranging from early 15th to early 20th century constructions and showing signs of distress and exposed to relatively high traffic vibrations were identified and examined. Vibration, noise and crack movements were monitored and soil conditions at each site were examined and traffic flow levels recorded. English Heritage, which has responsibilities for historic buildings and monuments of national importance, collaborated in this research by carrying out structural surveys of the buildings and by providing written reports of the observations. Table 6 provides descriptions of the buildings and includes details of approximate age and significant alterations that had been made to the structure of the building. The sites were selected to represent 'worst case ' conditions where it was considered that by virtue of the combination of high vibration levels, soils and building conditions, there was some potential risk of vibration damage occurring.

Overall the results showed that peak vibrations were above the level of perception at all but one site. The damage surveys identified a range of defects in the building ranging from cracks in plaster finishes to more substantial structural damage resulting from foundation settlement. In all cases it was concluded that the main causes of the damage observed was not traffic vibration. Full details of each case study are given in references [9] and [10].

Table 6: Description of heritage buildings

Site number	Description	Number of stories	Construction	Significant alterations	Approximate age
1	Shrimpers cottage in terrace	2	Brick	None	Late 18th C
2	Detached house	2	Brick	None	Mid 19th C
3	Cottage	2/3	Brick	Ground floor converted to shop	Early 19th C
4	Large house	2	Brick	Ground floor converted to public bar	Early 18th C
5	Georgian town house	4	Stone	Ground floor converted to shop	Mid 18th C
6	Large parish church	–	Stone	Spire added in 16th C	Early 15th C
7	Cottage	2	Timber-framed with brick extension	Porch and bell cote added in 19th C Mid 20th C extension	15th C
8	Large farmhouse	2	Stone and brick	Built as an inn converted to dwelling	Early 20th C

5. CONCLUSIONS

This paper gives a brief summary of a series of detailed studies of the effects of traffic-induced vibrations on people and buildings. The main conclusions are:

1. A high proportion of those people living next to busy roads are bothered by traffic vibration in the home. The majority of residents interviewed in a survey on traffic vibration said they were bothered by vibration because they thought it could cause damage to their properties.

2. The $L_{A10,18h}$ average noise measure can be used to predict the percentage botherd by airborne vibration.

3. Ground-borne vibration affects only a small proportion of residents. However the peak levels of these vibrations at building foundations can be relatively high, especially where the underlying soil is soft and houses are close to significant road surface irregularities.

4. The studies of traffic vibration damage show there is no evidence to support the assertion that traffic vibration has a significant damaging effect on buildings.

6. REFERENCES

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