Proceedings of The Institute of Acoustics

THE EFFECTS OF TRAFFIC-INDUCED VIBRATION ON HISTORIC BUILDINGS

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INTRODUCTION

For many years the importance of preserving historic buildings has been recognised, not just by historians and connoisseurs of architecture but by an ever increasing percentage of the general public. The prime reason for this is to conserve evidence of our heritage and social development for academic, cultural, aesthetic or commercial purposes. However, more recently, the view has been widely expressed that many old buildings, if they can be converted, renovated or just properly maintained, can provide better and more desirable homes or offices than do some of the large characterless estates and tower blocks that have been built since the war.

About one tenth of the U.K.'s Listed Buildings are situated in London and although they are only a small percentage of the total number of the area's buildings, by virtue of the way in which communities have grown up, they are more likely to be located in heavily trafficked areas. In the Greater London area, Greenwich, Harrow-on-the-Hill, and Blackheath are all fine examples of old villages or town centres where concentrations of buildings of historic interest are to be found around main roads and junctions. Hence, along with all the other adverse factors with which old buildings are faced, many are also the victims of potential damage from heavy road traffic. This may take several forms but perhaps the most often mentioned and the cause of most public concern are direct impact damage, caused particularly where large lorries try to manoeuvre through narrow streets and damage by vibration which is the subject of this paper.

Traffic-induced vibration has been the subject of many studies, most of which have concluded that the vibration levels found within buildings are insufficient to cause significant damage. However, very little work has been carried out on the effect of long-term vibration on buildings of old types of construction which can vary quite considerably from those which today's technology can produce. Therefore, because in London, there is perhaps the unique combination of high traffic flows and many buildings worthy of preservation, it was felt important to carry out a study of the effects of vibration on historic buildings.

The study involved the location in any one area, of two buildings of a similar age and construction, one being along a busy road - the test site - whilst the other is set away from traffic and thus acts as a control - the control site. By careful selection of sites it was hoped to ensure that the only difference between the two buildings chosen would be the level of noise and vibration to which they were exposed.

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Noise and vibration measurements were made at each pair of sites by the Scientific Services Branch of the GLC, whilst the Historic Buildings Division of the GLC carried out surveys of the properties to look for any significant differences in the state of structural or architectural condition of the buildings which could be attributed to vibration effects. By these means it was hoped to associate degree of damage (or lack of it) to measured vibration levels.

This paper presents the results of the noise and vibration surveys but the results of the structural surveys will be presented to Conference.

MEASUREMENT SITES

The sites for study were suggested by the Historic Buildings Division and those chosen for the pilot survey were:-

Greenwich Hospital Estate - 3 storey buildings with basements, mid C19th, Grade II listed

Vauxhall Cross - 3 storey buildings with basements, late C18th/early C19th, Grade II listed

Hampton - 2 storey cottages, C18th, Grade II listed.

NOISE AND VIBRATION MEASUREMENTS

Because of the need to consider cumulative effects of the vibration and to compare levels at two sites, vibration velocity was constantly monitored over a 24-hr period and various parameters were calculated and printed out every 15 minutes using a statistical analyser. The 15 minute print-out recorded L_1 (to give an approximation of the maximum level experienced), L_{50}, and an energy average, L_{eqv}, all in logarithmic terms using the standard equivalence. The later parameter was thought to be useful, as at the low vibration levels with which we are concerned, it seems likely that the total energy input to a building is an important factor in determining its reaction over a long period.

To ensure that the vibration detected was caused by traffic and not by internal plant or other sources, external noise was also measured over the 24-hr period, again obtaining a print-out every 15 minutes. In addition a continuous time history of the noise and vibration levels was also obtained. Because of the need to locate the external microphone where it could not be tampered with, the noise was measured at an upper storey. To intrude as little as possible into people's use of their homes, vibration measurements were made in the same position, in most cases placing the accelerometer on an external structural window ledge.

To provide further information about the pattern of vibration levels over the building, short-term 3-directional measurements were made at the 24-hr measurement position and at other points over the facade. The measurements were made simultaneously in 3 mutually perpendicular directions: vertical, horizontal and perpendicular to the wall and horizontal and parrallel to the wall, and were recorded onto a 4 channel tape recorder for subsequent analysis.

NOISE AND VIBRATION RESULTS

Using the 24-hr measurements of noise and vibration, various relationships between the two sets of results obtained for each building were investigated. For all buildings, the correlation co-efficients were high, showing a positive relationship between noise and vibration. In each case a linear regression analysis using sound pressure level and the logarithm of the vibration velocity was found to give the best (or equal best) fit. The resulting relationships are being studied.

By comparing the short-term measurements with the value occurring at the same time at the 24-hr position and using the directionality relationships found for each measurement point, estimates of the 24-hr averages at each of the other measurement points can be made. Using the same, admittedly simplistic, assumption estimates of the maximum L_1 occuring during the day can also be made. Hence an approximation to the peak particle velocity can be obtained.

Tables 1, 2 and 3 give for the Greenwich, Vauxhall, and Hampton sites respectively, the L_{10} values of the external noise, and for each measurement position, the 24-hr averages of the vibration velocity - based on an equal energy principal - and an estimate of the peak particle velocity.

Table 4 lists the relationships between velocity levels in the 3 perpendicular directions for all measurement points.

DISCUSSION

In all cases, the vibration levels found are much below the values which are normally associated with the occurence of architectural damage. The directional relationships show that the highest levels of vibration are to be found in a plane horizontal and perpendicular to the walls for storeys at and above the ground whereas in enclosed basements the maximum vibration is found in the vertial direction. (The basement of the control site at Greenwich does not show this pattern, but at this property the basement is in fact open to the street front, but below ground level). This would tie in with earlier work (References [1], [2]), which suggests that relatively high vibration levels can be induced into buildings by air-borne noise. It is thought that this movement is coupled into the structure via windows and, to some extent, doors, but this, of course, cannot be proved from the present results.

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Greenwich Sites
The test site is 2m from the kerb edge of a busy road. The vibration levels are such that people in the building would certainly be able to perceive the vibration. It is interesting that the directional behaviour of the vibration does not vary significantly up the building and this is being investigated. Vibration levels found at the control site should be unlikely to cause concern, although the timber floors did appear to resonate under certain circumstances.

Vauxhall Sites
These sites proved to be very interesting, not least because the building chosen as the test site (8m from kerb edge) proved to be subject to lower levels of vibration, than the control site (39m from kerb edge), despite being exposed to a relatively high noise level. In both buildings the levels of vibration will be clearly perceptible (this was confirmed by the occupiers). The results of the structural survey are eagerly awaited. The directional relationships again show that the horizontal component of vibration is larger at storeys above the ground whilst the vertical component is greater below ground level. However, the levels at the control site are much more heavily dependent on the horizontal component of vibration.

Hampton Sites
The test site is 1.5m from the edge of the kerb. The levels are clearly perceptible and on the upper floor probably quite disturbing. The control site should not suffer any problems from vibration.

CONCLUSIONS

1. The vibration levels measured during the course of the study are well below the values which are normally associated with the occurence of architectural or structural damage.
2. For storeys at or above ground level, vibration in the horizontal plane, perpendicular to the facade, dominates.
3. Buildings situated closest to a busy road do not necessarily experience the highest levels of vibration.
4. This limited pilot survey of noise and vibration levels has provided a useful base of information with which to compare the results of the structural surveys. It is hoped that the investigation can be continued to cover other types of constructions and ages of properties.

REFERENCES

[1] D.J. Martin et al., 'Measurement and analysis of traffic-induced vibrations in buildings', TRRL Supplementary Report 402 1978
[2] C.J. Bangham and D.J. Martin, 'Vibration nuisance from road traffic at fourteen residential sites', TRRL Laboratory Report 1020 1981

ACKNOWLEDGEMENT

This paper is published with the permission of the Head of Scientific Services of the Greater London Council but the views expressed are those of the author and not necessarily those of the Council or its Departments.

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Table 1: Greenwich Sites

	Test Site		Control Site	
L_{10}	79 dB(A)		68 dB(A)	
Vibration Velocity - Vertical direction - mm/s				
	24-hr average	Estimated p.p.v.	24-hr average	Estimated p.p.v.
Attic	0.044	0.33	N/A	N/A
2nd floor	0.015	0.10	0.008	0.07
1st floor	0.010	0.07	0.009	0.05
Ground floor	0.020	0.15	0.012	0.06
Basement	0.007	0.06	0.004	0.03

Table 2: Vauxhall Sites

	Test Site		Control Site	
L_{10}	77 dB(A)		70 dB(A)	
Resultant vibration velocity - mm/s				
	24-hr average	Estimated p.p.v.	24-hr average	Estimated p.p.v.
2nd floor	0.07	0.64	0.08	0.45
1st floor	0.05	0.28	0.07	0.33
Ground floor	0.04	0.27	0.08	0.48
Basement	0.02	0.10	0.02	0.14

Table 3: Hampton Sites

	Test Site		Control Site	
L_{10}	74 dB(A)		71 dB(A)	
Resultant vibration velocity - mm/s				
	24-hr average	Estimated p.p.v.	24-hr average	Estimated p.p.v.
1st floor	0.06	1.04	0.005	0.05
Ground floor	0.03	0.17	0.004	

Table 4: Directionality Relationships

Expressed as ratio of vibration velocity

Vertical: Horizontal, perpendicular to wall: Horizontal, parallel to wall.

	Test Site	Control Site
1. Greenwich		
2nd floor	1 : 1.8 : 0.9	1 : 2.3 : 1.4
1st floor	1 : 1.7 : 1	1 : 1 : 0.6
Ground floor	1 : 1.6 : 0.7	--
Basement	--	1 : 1.2 : 1.3
2. Vauxhall		
2nd floor	1 : 2.8 : 2.1	1 : 4 : 1.3
1stfloor	1 : 1.6 : 1	1 : 3.4 : 1
Ground floor	1 : 1.9 : 1	1 : 3.2 : -
Basement	1 : 0.5 : 0.5	1 : 0.6 : 0.9
3. Hampton		
1st floor	1 : 4.7 : 0.7	1 : 1.7 : 0.6
Ground floor	1 : 1.8 : 1.9	1 : 1.2 : 0.5