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MONITORING THE EFFECTS OF SIMULATED ROAD TRAFFIC VIBRATIONS ON A TEST HOUSE - RESULTS

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INTRODUCTION

An experiment which was carried out under contract to the Transport and Road Research Laboratory was designed to determine whether simulated traffic vibration caused damage to a specimen house and if so, what damage mechanisms were involved. The structure selected for the study comprised a pair of semi-detached houses, approximately 90 years old, founded on a loose to medium dense sand. Vibration simulation was split into two parts. Airborne vibration was simulated by a loudspeaker system, mounted in the side of a lorry and connected to a computer. Groundborne vibration was achieved using a geophysical vibrator which impacted the ground.

The main aim of the work was to assess whether road traffic vibration caused damage to houses. In order to make this assessment, four types of monitoring were carried out. These comprised a site investigation, a structural survey, a programme of vibration monitoring, and periodic measurements of movement and damage. Full details of the techniques employed are provided in the previous paper (1). Further results on the response of of building elements to the simulated vibrations are given in reference 2.

VIBRATION MONITORING

Response of Structure to Groundborne Vibration.

The vibrations of the front facade of the structure in vertical and radial directions, with respect to the vibrator were studied. The peak levels measured are plotted on Fig.1.

On the foundations the vertical component attenuates with distance approximately in accordance with an inverse square root function. The pattern is mirrored at eaves level with some amplification, which is probably associated with the reduced dead load. This smooth response is unlikely to have introduced any severe stress concentrations into the structure.

The radial component demonstrates a very different pattern of behaviour. On the foundations, no significant attenuation is present. At eaves level, vibration peaks at either end of the structure, with a drop in level towards the middle. This pattern suggests that the main transmission of energy is taking place through the foundations.

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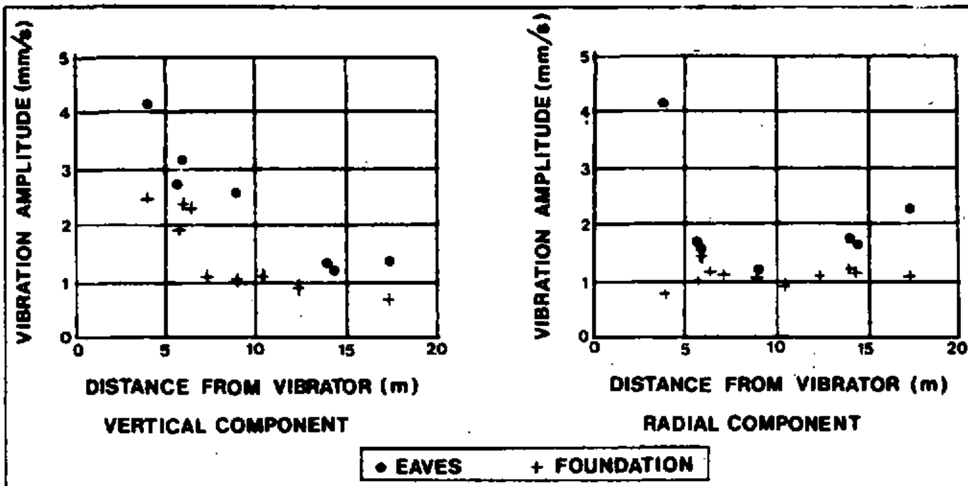

FIG. 1 VARIATION OF VIBRATION LEVEL WITH DISTANCE

At eaves level there is a large change in radial vibration level between the end of the structure and the adjacent measuring position. The restraint afforded by the chimney is probably a major cause of this. Such a sudden change in vibration level is likely to be associated with stress concentration.

Fig.2 plots the time taken for the wave front to reach each geophone station against distance from the vibrator. This shows the radial component to be travelling approximately 25% faster than the vertical component.

Measurements were also undertaken on individual structural elements. The end wall of the structure was found to be vibrating at up to 11 times the amplitude measured on its foundation. New cracks were observed internally both on this wall and at the adjacent wall/ceiling joint.

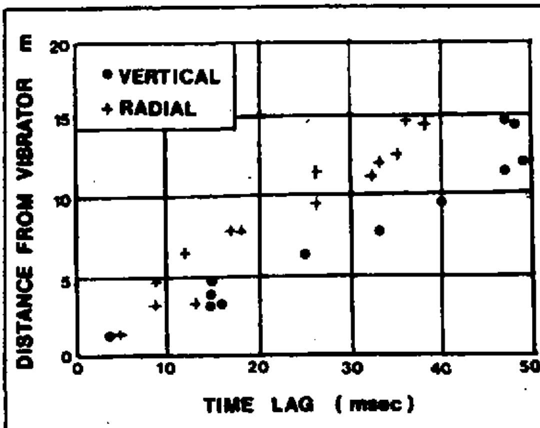

FIG. 2 WAVE ARRIVAL TIME

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Response of Structure to Airborne Vibration

The airborne vibration source gave a noise level of 110dB(A) outside the window and 92dB inside. A peak vibration response of 131mm/s was measured on the window pane adjacent to the noise source. However, the highest vibration level resulting elsewhere within the structure was less than 2.5 mm/s (in a suspended floor). Response of the house foundation was negligible. No damage was recorded. Since the simulation of airborne vibration was devised as a "worst case", we conclude that in general any damage resulting from this source would be superficial. For even slight damage to occur, stress concentrations would probably have to be present prior to exposure.

MONITORING OF MOVEMENT

Level Survey

Some scatter occurred in the results of the level survey, limiting its accuracy to approximately 0.3mm. Within this range no detectable settlement or heave occurred at any time during the experiment.

Interferometric Photography

This technique showed a lateral movement of 0.4mm in one small area of the house facade. However, the resolution of the system is only $\pm$0.2mm, rendering this result only just significant.

Crack Survey

A small amount of additional cracking of plaster occurred during the experiment, mostly at wall/ceiling junctions. Of the 40 existing cracks surveyed for movement, only 5 showed a sustained change in width exceeding 0.1mm. First floor ceiling crack patterns are shown on Fig 3.

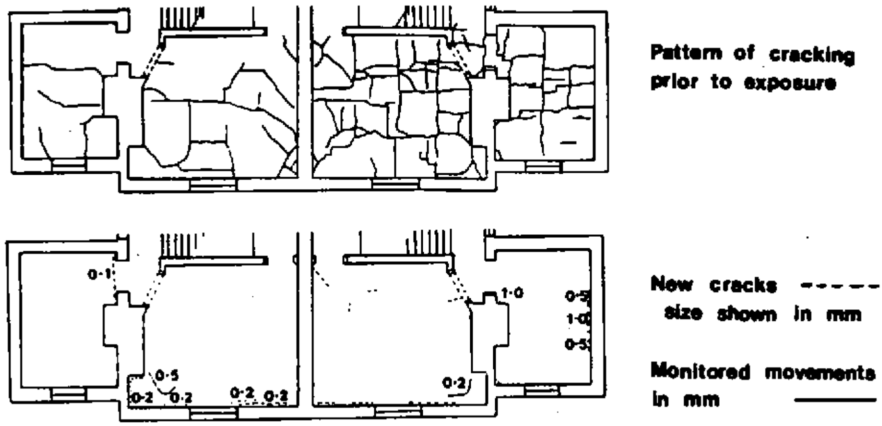

FIG. 3 CRACK PATTERNS IN FIRST FLOOR CEILING

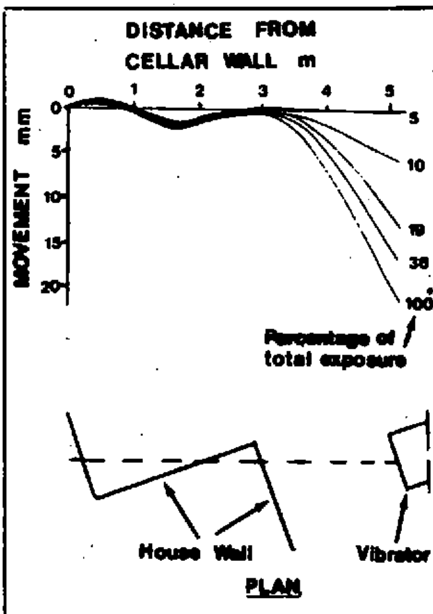

FIG. 4 SOIL MOVEMENTS

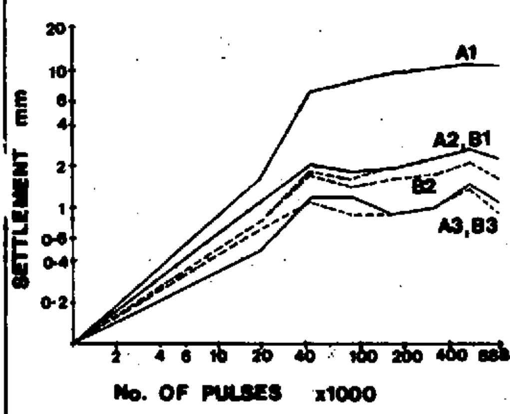

FIG. 5 TEST STRIP MOVEMENTS

Soil Movements

Although a settlement of 22mm was recorded within the soil under the vibrator pad, little movement was evident beneath the house foundations. Figure 4 shows the movements recorded by one of the electrolevel strings. In contrast, settlements in the range 1-11 mm were measured on the test strips. The pattern of these settlements is shown on Figure 5.

All six test strips tilted to some degree. In each case, two levelling stations were monitored. The settlements measured are tabulated below:

TABLE 1 - TILTING OF TEST FOUNDATION STRIPS

Strip ref	Dead Load Ratio	Vibration Level Ratio	Settlement (mm) near edge to vibrator	far edge from vibrator	Settlement Ratio (max/min)
A1	2.0	1.2	14.0	7.0	2.0
A2	1.0	1.4	2.1	2.4	1.1
A3	0.5	1.4	0.6	1.6	2.7
B1	2.0	1.2	2.9	1.5	1.9
B2	1.0	1.2	1.4	1.7	1.2
B3	0.5	1.3	0.6	1.2	2.0

Note: Dead Load and Vibration Level ratios are absolute values divided by corresponding values on house foundation.

Final Site Investigation

At the end of the experiment, a second site investigation was conducted, to assess the density of the soil beneath the vibrator the house foundation and the test foundation strips. In all locations, the measured densities fell within the range assessed for the site prior to the simulation. (See Fig.6).

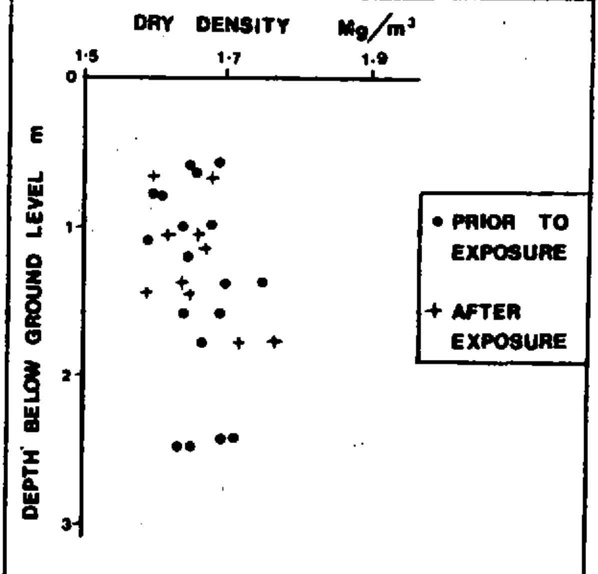

FIG. 6 SOIL DENSITY

SUMMARY OF POSSIBLE DAMAGE MECHANISMS

The following mechanisms for vibration-related damage to buildings are suggested:

(i) Compaction or migration of soil resulting in differential settlement and damage.

(ii) Damage to structural elements due to high local vibration levels. This could occur either as "trigger damage" or as a fatigue effect.

(iii) Damage due to changes in structural stiffness or mass, leading to sudden changes in vibration level.

(iv) Damage to plaster at wall/ceiling joints due to vibration of floor and ceiling joists.

(v) Roof damage, due to high vibration amplitude in rafters.

(vi) Damage to windows and surrounding plaster due to airborne vibration.

DISCUSSION

Soil Movements

Very little movement of the test structure or the underlying soil was recorded despite a potential for up to 20mm of settlement by densification of the soil. The test foundation strips, however, did settle, by varying amounts. No soil densification was recorded anywhere on the site. It therefore appears that the vibration levels being generated were insufficiently high to densify this particular soil.

The settlement under the test foundation strips appeared to be associated with localised rotational movements within the soil. The main structure was unable to undergo similar movements due to the difference of scale. A shearing plane beneath one of the test strips would be contained within the top layer of loose uncemented sand. For part of the house to rotate in a similar fashion, soil mobilisation would be necessary to a greater depth.

There may be other circumstances in which settlement of a full sized structure might occur. These are summarised below:

(i) Different soil types eg. saturated sand, soft clay or peat.

(ii) Other ground conditions. eg no cemented layer.

(iii) Different structural conditions. Individual footings of the test house were unable to rotate due to the restraint afforded by the structure. Had any single facade been poorly supported, localised rotational settlement might have occurred.

Movements within the Structure

The most significant movements within the plaster (new cracks or movements in existing ones) occurred in the end wall of the house facing the vibrator, and in ceilings close to the chimneys. The overall level of damage was very slight. It is probable that in a normally decorated house, none of the damage recorded would have become evident.

The slight movements which did occur appear to have been as a result of a fatigue effect since they appeared relatively late in the simulation period. No "trigger damage" was recorded in the experiment. This may have been due to the extensive cracking which already existed, which would have relieved any stress concentrations within the plaster.

CONCLUSIONS

This study involved an extensive and wide ranging series of experiments. However in drawing conclusions from the work the particular characteristics of the site must be borne in mind as they will have had a considerable effect upon the results recorded.

Damage to buildings caused by road traffic vibrations will, in our opinion, result from: differential settlement in the underlying soil; trigger damage, or fatigue effects. In this experiment only the last of these three mechanisms was observed, and the resulting damage was limited to slight cracking of plaster. Bearing in mind the particular site conditions and the limited damage actually observed the following conclusions can be drawn:

i. Airborne vibration from traffic is unlikely to lead to structural damage. Windows and nearby plaster under stress could be damaged by trigger mechanisms though none were generated during this study.

ii. It is unlikely that structural damage would result directly from traffic vibration except in cases where settlement or trigger damage occurred.

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iii. The test structure suffered no "trigger" damage. In a house with less extensive plaster cracking the risk of vibration induced trigger damage to plaster would be greater. We consider that structural damage is highly unlikely to result from this mechanism.

iv. Differential settlement had been predicted prior to the experiment, but none was actually recorded. This appears to have been a function of the particular conditions existing on the site. Other soil types and geometries exist in which differential settlement would be more likely, and under such circumstances some damage might result. Even on a soil such as that at the test site, it is possible that settlement might have been observed due to localised rotational movements had the facades of the structure been less well tied together.

v. Previous work in the field of vibrations and buildings suggests that maximum nuisance to occupants is caused by rattling windows and vibrating floors. The vibration monitoring work undertaken during this experiment showed that these effects are not directly related to vibrations in foundations and walls. Therefore an increase in traffic related nuisance does not necessarily imply an increase in the risk of damage. In our view, for any risk of damage to exist at all due to traffic induced vibration, considerable nuisance would have to be present.

REFERENCES

1. R A Hood and C P Marshall, 'Monitoring the Effects of Simulated Road Traffic Vibrations on a Test House - Experimental Methods', - paper presented at 'Acoustics '87', (1987).

2. G R Watts, 'The Response of Building Elements to Simulated Traffic Vibrations' - paper presented at 'Acoustics '87', (1987).

The authors of this paper are employed by Travers Morgan Planning. Work reported herein was carried out under a contract placed on them by the Transport and Road Research Laboratory. The views expressed are not necessarily those of the Department of Transport.