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GROUNDBORNE VIBRATIONS GENERATED BY HGVs - EFFECTS OF SPEED, LOAD AND ROAD PROFILE

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INTRODUCTION

Traffic induced vibrations in buildings close to heavily trafficked roads are sometimes considered to be a serious type of environmental nuisance even though examination of such buildings suggests that these vibrations are very unlikely to cause damage(1). A recent survey has shown that traffic vibration can be an important source of annoyance and HGVs were often mentioned as the chief cause of the problems(2). As part of the TRRL's programme of research into the effects of traffic vibration on people and buildings, the factors affecting the generation and propagation of groundborne vibrations are being studied. Past research has highlighted the importance of suspension design(3,4,5) and present work is aimed at testing current designs of suspension systems and examining the effects of design modifications. This paper describes some initial tests carried out on the Laboratory's research track to determine the importance of suspension design, speed, load and road profile in influencing the peak levels of vibration produced at the road surface. At a later stage it is planned to relate the present results to variations in both measured and calculated dynamic axle loads using computer models that are presently being developed.

VEHICLES TESTED

In these initial tests, four heavy goods vehicles were tested over artificial humps on the research track. Two were articulated vehicles (A and B) both powered by a Daf 3300 tractor unit with multileaf springs on each of the two axles (see figure 1 for axle layout and suspension details). The trailer of vehicle A had tandem single leaf springs coupled by pivoted beams. Vehicle B had a tanker trailer with twin axles on air suspension (Dunlop Stabilair). Vehicle C was a four axle rigid tanker with twin steering axles with multileaf springs and twin rear drive axles. These rear axles were coupled by single inverted multileaf springs which were pivoted at the centres. Vehicle D was a two axle flat bed lorry with single multileaf springs on the front axle and double multileaf springs on the rear. The vehicles were tested loaded close to the legal limit for each axle and in addition (except for vehicle D) with half these loads and unladen. Table 1 lists the static axle loads for each load condition.

TEST PROFILES

The dimensions of the cross-section of each road surface test hump are given in figure 2. The humps were constructed from plywood and firmly bolted to a section of the track at a position where vehicle speeds of up to 96km/h could be achieved. The test track humps were designed to represent the conditions resulting from poorly backfilled trenches on public roads. Measurements of the profile of the road surface in the wheel paths within 5m of the humps

Table 1. Static axle loads (Tonnes)

Unladen \ Axle		1	2	3	4	Total Vehicle
A	Unladen	5.17	3.87	2.09	2.07	13.20
	½ Laden	5.88	6.95	5.05	4.71	22.59
	Full	6.39	9.47	9.08	7.78	32.72
B	Unladen	5.23	3.63	1.82	1.87	12.55
	½ Laden	5.91	7.26	4.91	4.84	22.92
	Full	6.51	9.57	8.71	7.94	32.73
C	Unladen	3.35	3.34	4.15	4.19	15.03
	½ Laden	4.10	4.19	6.68	6.69	21.65
	Full	4.69	5.03	9.31	9.27	28.29
D*	Full	6.10	9.70	-	-	15.80

*Tested when fully laden only

showed a variation of height of approximately +/- 7mm. This was considered to be representative of many stretches of urban road between distinct surface irregularities.

MEASUREMENT TECHNIQUE

Vibration measurements were taken, primarily, by recording particle velocity at the track surface adjacent to the test humps at distances of 2 and 6m from the nearside wheel track (see figure 3). The 6m distance was chosen as typical of the distance of some older terraced properties from traffic where vibration effects can be perceptible and cause nuisance. At both measurement positions vertical, radial and transverse components were recorded using triaxial geophone arrays. In addition, vertical acceleration was measured at the 2m position to check the very low frequency content of the signal since the geophones were insensitive below approximately 5Hz. The signals from the geophones were conditioned using operational amplifiers and processed using a CED 1401 intelligent interface unit driven by a microcomputer. The signals were sampled at a rate of 1000/sec and the unit was programmed to scale and display all channels simultaneously immediately after sampling had finished. Figure 4 shows typical output traces. A modulated infrared emitter and sensor was used to detect the passing of each wheel across the profile. The event pulses generated by the infrared sensor were displayed alongside the vibration signals so that it was possible to relate vibration peaks to particular axles, or to groups of axles if these were closely spaced. The pulses were also used to compute the precise vehicle crossing speed on each test. After inspection the data were stored on floppy disk for later analysis.

The vehicle test speeds were 16, 48, 64, and 80 km/h (in early tests, runs were not made at 64 km/h). It was not possible to achieve the maximum speed with the four axle rigid tanker (vehicle C). Generally three runs were made at each speed. In the subsequent analysis the peak vibration levels for each channel produced by each axle or set of axles were computed together with the crossing speed and stored with vehicle identification, load condition and profile data.

RESULTS AND ANALYSIS

These initial results are concerned with the vertical peak particle velocity (PPV) recorded at the 6m geophone position. The peak vibration and acceleration levels at 2m were very highly correlated with levels at 6m. Figure 5(a) to (d) show the variation of PPV with speed for the four fully laden test vehicles crossing the standard hump. Peak levels produced by each axle or group of axles are shown. Where axle spacing was small it was not always possible to distinguish the effect of each axle. For example the PPV for the trailer axles as a group were computed for vehicles A and B. The maximum level for each vehicle changes with increasing speed from 16 to 80 km/h by at least a factor of three. For most of the test conditions the PPVs were above the perception threshold of 0.3mm/s so the vibrations would probably be felt. Generally the drive axles, which carry the greatest static load, produced the highest vibration levels whereas the steering axles, carrying the lightest loads, produced the lowest PPVs. However static load is not simply related to PPV as suspension type is also important. For example, vehicle C produced significantly lower vibration levels for comparable speeds than the other vehicles despite the fact that the static load of the drive axle was similar to the other vehicles. The reasons for this are not clear but it may result from lower tyre stiffness. The single wide tyres on the rear axles of vehicle C would be expected to produce lower dynamic loads than twin tyres on the drive axles of vehicles A and B (4). However, this can only partly explain the observed behaviour since the pivoted multileaf suspension system on vehicle C should be less well damped than those of the other vehicles and this might be expected to increase axle loads and vibration levels.

The effects of load were examined using vehicles A, B and C (vehicle D was only tested fully laden). Figure 6 shows the effects of various load conditions when the vehicle was driven at 48km/h over the standard hump. Surprisingly, for vehicles A and C the PPVs are highest for the unladen and not the laden condition. For vehicle A it can be seen that it is the trailer axles which are producing the highest levels in the unladen tests, and not the drive axles which generated most vibration in the laden tests. At this speed it is possible that the unladen rear suspension is exhibiting a resonance effect with the trailer wheels possibly leaving the running surface. The speed, axle spacing and profile may have been such as to strongly excite the wheel hop mode of vibration. Theoretical work has shown that for a coupled axle system resonance is likely to occur at a higher vehicle speed when the vehicle is laden(5).

In the present tests there were significant interactions with speed and loading conditions. At the higher speed of 80km/h, PPVs were greatest for the fully laden condition although vehicle A produced higher vibration levels when unladen than when partly loaded. However, the variations with load were generally small compared with speed effects. The variations between maximum PPV levels produced by a particular vehicle between the unladen and fully loaded condition were no more than about 25 percent. This is in agreement with the findings of a review of dynamic loading caused by vehicle suspensions(4). It was concluded that although the peak dynamic wheel load increases with static axle load the variation, or dynamic component, of the wheel load is little affected. It is this dynamic component that is most likely to influence the maximum levels of vibration generated.

The effects of hump dimension were analysed using data from tests at 48km/h with vehicles fully laden (see figure 7). The vibration levels produced by vehicles running only on the level surface were all insignificant, being below the perception threshold. The standard and wide humps produced similar PPVs, being of a similar height. However the high hump, having the same width as the standard but being over twice as high, produced significantly higher levels. In the case of vehicle A, the high hump produced peak levels of nearly 1.8mm/s, approximately double the level produced by the standard hump. Using the high hump, vibration levels inside the vehicles were generally severe even at low speeds and because of the risk of equipment damage, tests were not conducted with vehicle B or C. At higher and lower speeds, vibration levels produced by the track surface remained below perception level and again the high hump produced the largest vibrations.

Further tests are planned with a triaxle trailer and with both rubber and different types of air suspension system. In addition, a trench has been constructed across the track to provide a further type of surface profile. The dimensions of the trench have been derived from measurements of uneven patches on public roads which have caused perceptible vibrations in buildings.

CONCLUSIONS

It is concluded from this preliminary study that the peak vibration levels generated by a vehicle axle are not simply related to the static axle loading. For example, at a speed typical for urban roads, two vehicles generated greater vibration when unladen than when fully loaded. However, the variation of maximum vibration level with load were generally modest. In contrast, vibration levels increased greatly with speed and height of profile. Further types of suspension system will be studied since it is clear from these initial results that significant differences in the peak level of vibration produced by different suspension types can be expected. None of the vehicles running on a relatively smooth surface produced vibration levels that would have been perceptible at a distance of 6m from the nearside wheel track. Some distinct irregularity in the wheel paths is required to produce perceptible vibrations under these test conditions.

ACKNOWLEDGEMENTS

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REFERENCES

(1) G.R. Watts, 'Traffic vibration and building damage - TRRL papers presented at Acoustics '87', TRRL Research Report RR146, (1988).

(2) G.R. Watts, 'Vibration nuisance from road traffic - results of a 50 site survey', TRRL Laboratory Report LR1119, (1984).

(3) D.R. Leonard, J.W. Grainger and R. Eyre, 'Loads and vibrations caused by eight commercial vehicles with gross weights exceeding 32 tons (32.5Mg)', TRRL Laboratory report LR 582, (1974).

(4) J. Page, 'A review of dynamic loading caused by vehicle suspensions', TRRL Supplementary Report 82 UC, (1974).

(5) J. Page, 'Dynamic behaviour of two linked-twin-axle lorry suspension systems: a theoretical study', TRRL Laboratory Report LR 581, (1973).

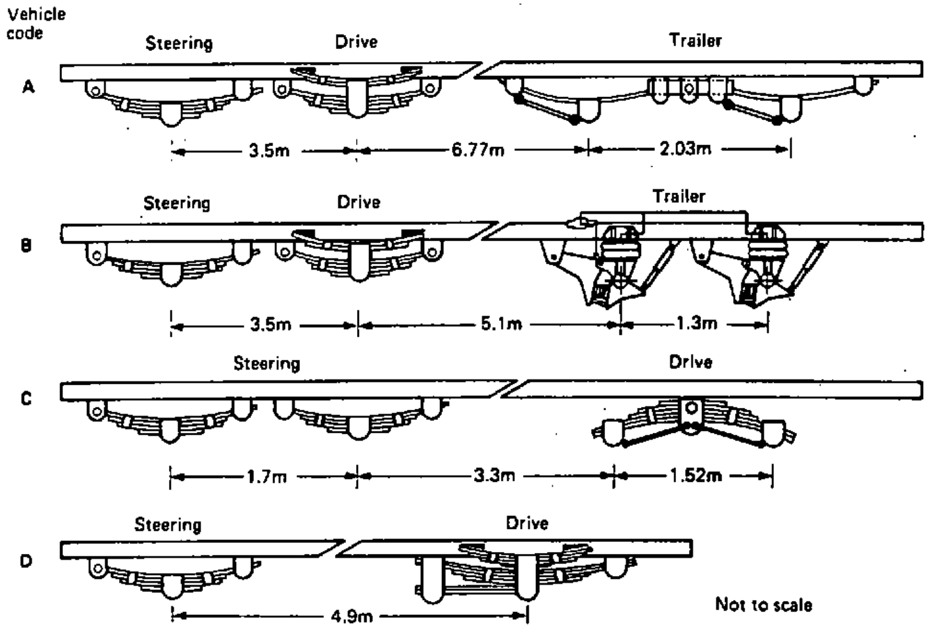
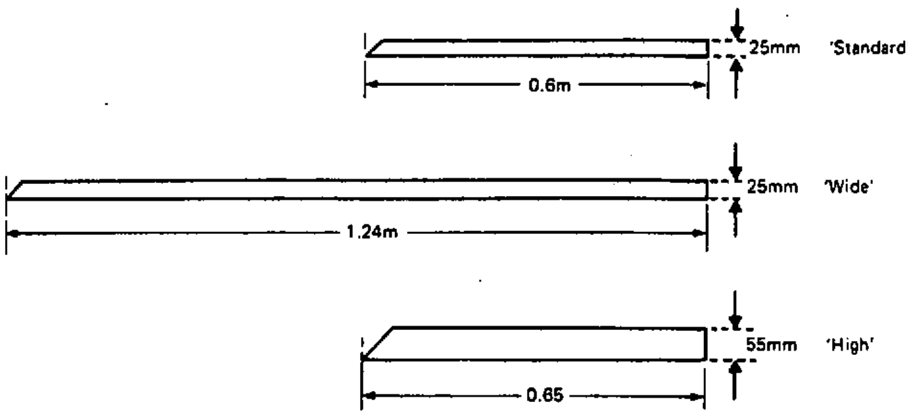


Fig. 1 Suspension details



Note: The track surface had a level surface to within ± 7mm within 5 metres of the mid profile position

Fig. 2 Test humps

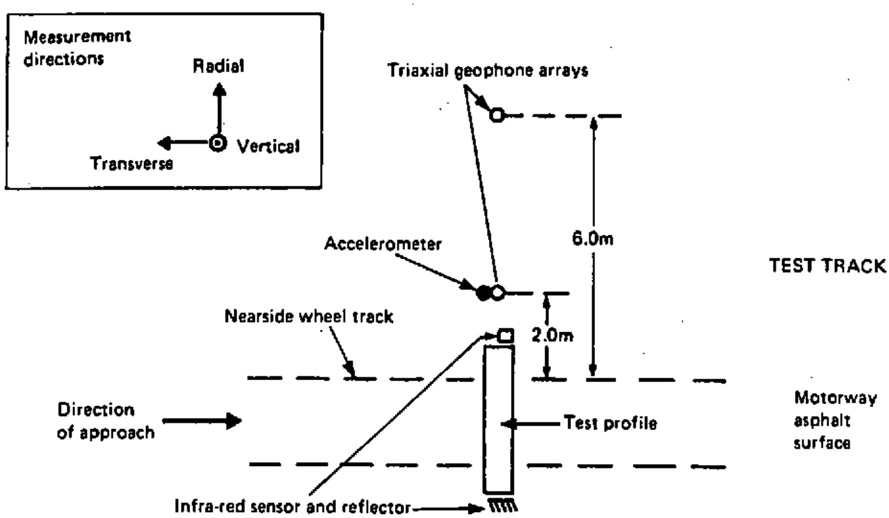


Fig. 3 Location plan of geophones and accelerometer

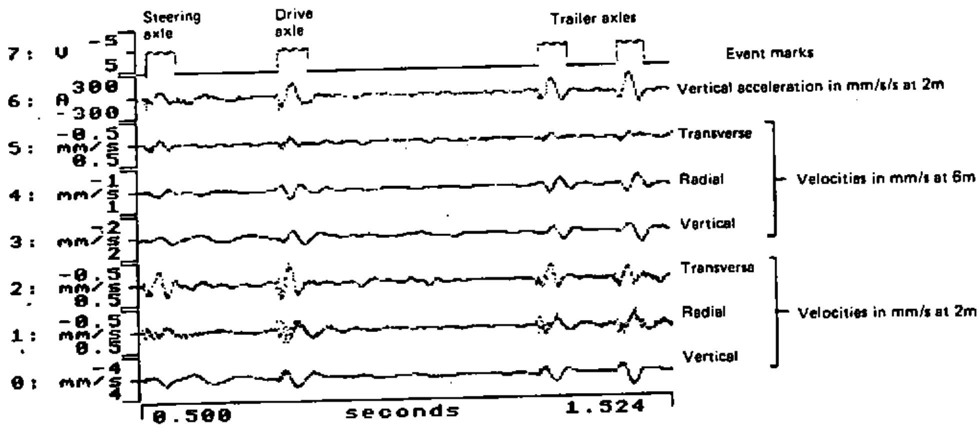


Fig. 4 Example of output trace – vehicle A travelling over the standard hump at 48 km/h

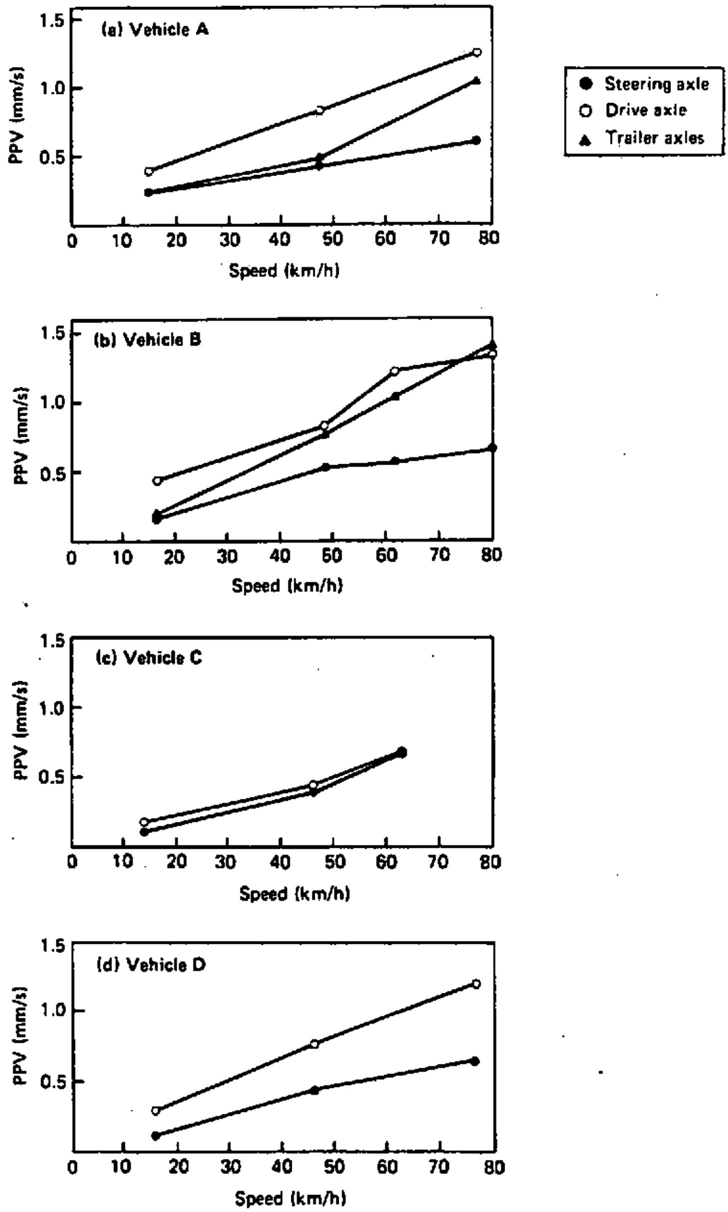


Fig. 5 Variation of vertical peak particle velocity with speed using fully laden vehicle with standard hump

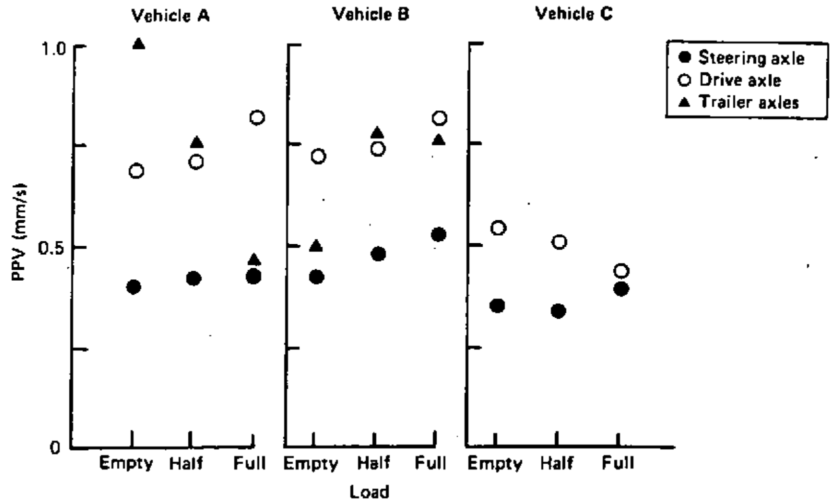


Fig. 6 Variation of vertical peak particle velocity with load at 48km/h using standard hump

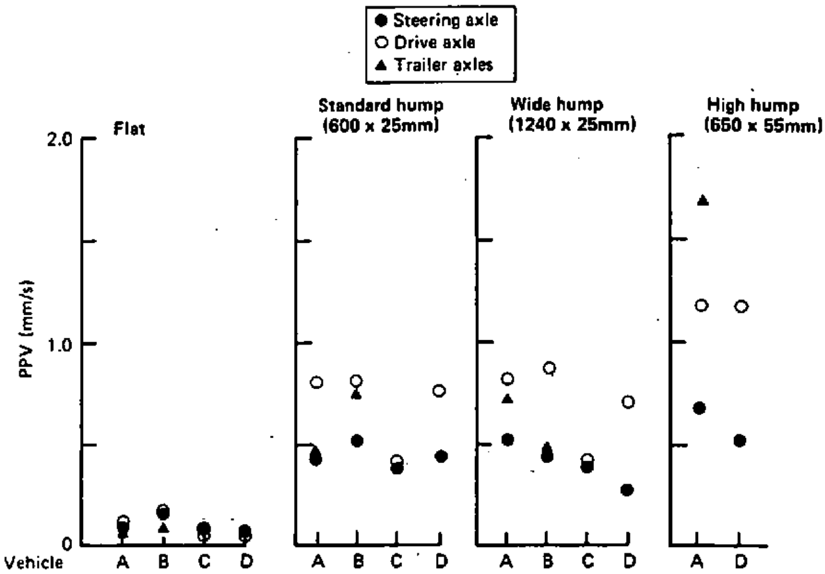


Fig. 7 Variation of peak particle velocity with hump dimensions at 48km/h using fully laden vehicle