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LOW FREQUENCY NOISE UNDER INTERRUPTED FLOW CONDITIONS

D. GILBERT

TRANSPORT SECTION, IMPERIAL COLLEGE LONDON

In 1978 SCPR published the results of a social survey of attitudes to road traffic usually referred to as the National Environmental Survey (1). The Survey, carried out in 1972, was broadly representative of the adult population in England, and assessed, amongst other factors, the disturbance caused by traffic noise and vibration to people when indoors at home. The survey showed that whilst vibration was less widespread than noise it was considered to be a serious source of bother by those affected. The results were similar to those of an earlier study in Edinburgh (2) in which about one in ten of the sample considered 'noticeable vibration' to be prevalent.

In the Edinburgh study, carried out in 1969, crude measurements were made of both kerbside vibration levels and broad band low frequency sound levels. Vibration was measured using a shielded accelerometer the output fed via a cathode follower into a Dawe type 1433 Vibration meter set to the velocity scale. The traffic noise was filtered using a low pass filter (less than 100Hz) fitted to a Dawe 1400F sound level meter set to the C weighting scale. The analyses of recordings at some 150 sites was based on meter readings taken from time lapse films at 4 second intervals.

Mean vibration levels varied approximately linearly with traffic volume with the highest levels recorded in streets with substantial flows of heavy vehicles. In some locations these average levels were close to 0.015 in/s (0.0004m/s) the threshold of perception. Median flow frequency noise levels varied logarithmically with traffic volume reaching 90dBC in some locations. L_{10} levels were typically some 7 to 10 dBC higher than the corresponding median level. Traffic volumes ranged from 0 to 2500 mph and the proportion of heavy vehicles up to 30% of total flow.

In practice ground-borne vibrations tend to attenuate rapidly with distance from source and it is unlikely therefore that ground vibrations can cause perceptible structural vibrations in buildings located near to a well maintained road (3). However it is known that air-borne low frequency sound can induce building vibration and occupants of buildings exposed to high levels of low frequency sound may perceive vibration both directly and indirectly. Noise and vibration are closely related and not always distinguishable but in a recent, as yet unpublished, survey of attitudes to traffic along a heavily trafficked route which was subject to exceptionally high noise levels, both noise and vibration were identified as problems by residents and were a serious source of bother to almost 1 in 2 of those affected.

Problems with vibration are most likely to occur in urban areas where buildings are close to the road and overall traffic and heavy vehicle volumes are high, and flow patterns are frequently interrupted. Procedures exist for estimating traffic noise L_{10} levels under these circumstances (4) but there is also a need to develop an understanding of the way in which flow frequency traffic noise scales are affected by variations in traffic and which scales are most amenable to prediction.

THE EXPLORATORY STUDY

The procedure adopted for the purposes of this study was to measure low frequency noise and traffic parameters at a number of specially selected sites. The sites were chosen to minimise inter-site variations in measured levels which might result from differences in site propogation, absorption and reflection characteristics. Under these conditions the prediction model for low frequency noise could be related to traffic variables alone. The selection of roads was based on the need to cover a sensible range of urban traffic flows without incurring increased site variability at the higher flow rates. The microphone height was generally set 1.2m above roadway crown level. The microphone was generally set 1m from facade of buildings and, as far as practical, removed from the near kerb area to minimise vehicle breeze problems and 'near field' measurement problems.

The approach was

(i) record sound measurements at 32 urban sites using a high quality tape-recording system whose low distortion frequency range extended down to at least 10Hz

(ii) record traffic variables simultaneously during the normal 20 minute measurement peroid and measure other site characteristics

(iii) analyse the tapes extracting the required scales over relevant frequency ranges

(iv) use regression analysis to determine noise scale-traffic variable and noise scale-noise scale correlations

THE CHOICE OF VARIABLES

The noise scales

The choice of noise scale was explained extensively in a literature review by Hollingworth (5). Four criteria were used to judge the appropriateness of the frequency range: floor vibrations (free and forced) bodily effects, auditory effects, furniture and fittings etc. vibration. The choice of scale was between percentile levels (e.g. 10%, 50% etc) or energy equivalent levels (e.g. Leq Lnp etc). As a result of the literature review it was felt that the scale which would prcbably correlate most highly with general response to vibratory disturbance was that of L_{eq} (40-125) Hz. The full range of low frequency scales investigated are set out in Table 1. Other scales determined during the study included L_{10} (linear) L_{10} (A) and L_{eq} (A).

TABLE 1. Low frequency noise scales used in study

SCALE	EFFECTS COVERED
Wide band scales	
L_{eq} (5-63Hz)	bodily effects - general
L_{eq} (40-125Hz)	chest resonance plus floor vibration
L_{eq} (125-200Hz)	needed only for extended frequency
Narrow band scales	
L_{eq} (5-10Hz)	bodily organ resonance
L_{eq} (40-63Hz)	chest resonances

Choice of traffic variables

The choice of traffic variables was strongly influenced by the results of earlier studies of traffic noise under interrupted flow conditions (4) at Imperial College and a review of the literature on composition variables (6). After consideration of a number of variables (e.g. traffic flow, composition, speed, level of service, arrival patterns, etc) it was decided to measure only flow and traffic composition as follows

a) motor bicycles
b) cars
c) light commercial vehicles (unladen weight ≤ 3000Kg)
d) medium commercial vehicles (commercial vehicles with 2 axles and unladen weight > 3000Kg including buses and coaches)
e) heavy commercial vehicles (all commercial vehicles where the number of axles ≥ 3)

THE ANALYSES

As a first step in the analyses a number of noise scale correlations were undertaken. A summary of these correlations is set out in Table 2. The table shows that the preferred scale (i.e. Leq (40-125Hz)) correlates very highly with Leq (5-63Hz) for general bodily effects and Leq (125-200Hz) for general auditory effects. It does not correlate well with the one-third octave band at 16Hz; nor does it correlate particularly well with the narrow band scale L_{eq} (5-10Hz). However it was also found in the analyses that the scale Leq (5 - 63Hz) did not perform any better than Leq (40-125Hz) as a suitable surrogate for the narrow band bodily organ resonance effects (covered by Leq(5-10Hz)). The correlation coefficient for these two scales was 0.77 with a standard error of estimate of 3.0dB.

The table also shows a number of low frequency scale - broad band scale correlations. The object of this part of the analysis was to examine to what extent more easily measured scales could be used to predict broad-band low frequency scales. The table shows that values of Leq (40-124Hz) are highly correlated with broad band levels. Similar results were obtained for the two other broad band low frequency scales.

TABLE 2. Pearson production moment correlations for selected noise scales

Scale	Correlation with L_{eq} (40-125Hz)		
	Correlation coefficient R	Shared variance R^2	Standard error of estimate (dB)
L_{eq} (5-63Hz)	0.98	0.97	0.7
L_{eq} (125-200Hz)	0.91	0.83	1.5
L_{eq} (40-63Hz)	0.99	0.98	0.6
L_{eq} (5-10Hz)	0.73	0.53	3.3
L_{eq} (16Hz)	0.27	0.07	-
L_{10}(A)	0.94	0.88	1.4
L_{10} (linear)	0.97	0.96	0.8

The results of the analysis confirmed that L_{eq} (40-125Hz) acts as a convenient surrogate for the most obvious bodily auditory and room vibration effects. Further correlation analyses established first, that site layout variables were not significant determinants of low frequency noise levels and secondly, that the logarithm of flows of medium and heavy goods vehicles produced the best bivariate regression. Multiple regression analysis was then undertaken using the results of the bivariate regression and the approach adopted in earlier noise studies where vehicle types were weighted according to their impact on noise level (4). Two equations were developed one being termed the best 'theoretical' equation since one of its parameters would be difficult to predict. These equations were as follows

best practical equation

$$L_{eq}\ (40\text{-}125\text{Hz}) = 53.0 + 9.43 \log (Q + 10M + 40H)$$
$$R^2 = 0.87 \quad SEE = 1.49 \text{ dB} \qquad (1)$$

best theoretical equation

$$L_{eq}\ (40\text{-}125\text{Hz}) = 53.4 + 8.98\ (Q + 10M + 40H) + 0.0454\ (\%\ NTG)$$
$$R^2 = 0.92 \quad SEE = 1.2\text{DB} \qquad (2)$$

where

- Q = total hourly flow in mph
- M = medium commercial vehicles (vph)
- H = heavy commercial vehicles (vph)
- % NTG = proportion of commercial vehicles not using top gear

Within the 32 site data set a small number of sites had significant road gradients, at these sites low frequency noise levels were higher than at level sites with similar traffic characteristics. An investigation of residuals suggested the following tentative guidelines

Grade %	Additional correction to L_{eq} (40–125Hz)dB
0–3	+ 0.9 x gradient (%)
3–4	+ 2.7
5–6	+ 3.2

Based on the work of Martin (7) it is estimated that L_{10} (40-125Hz) levels will be some 2-5 dB higher than the Leq (40-125Hz) levels given by the above equations.

INTERPRETATION OF RESULTS

The results of the regression analyses can be compared with earlier prediction equations for broad band noise associated with interrupted flow (4).

$$L_{10}(A) = 40.9 + 11.23\ (Q + 8M + 12H) \qquad R^2 = 0.88\ \text{SEE}\ 1.17 \qquad (3)$$

If equations 1 and 3 are compared, the significance of the contribution heavy commercial vehicles to noise levels can readily be seen. In terms of low frequency noise a heavy vehicle is equivalent to about 40 cars or light vehicles. Even when volumes of heavy vehicles are relatively small they can have a dominant effect on L_{eq} levels.

The importance of heavy vehicles in the determination of 'vibration' nuisance is reflected in the results of studies carried out by the TRRL (8). A number of prediction equations for vibration nuisance were developed using both traffic variables and low frequency noise scales as explanatory variables. Two of these equations are set out below.

$$N = -17.92 + 0.2711\ \text{Leq}\ (63\text{-}125\text{Hz}) \qquad r = 0.78 \qquad (4)$$

$$N = 0.02 + 1.3528\ \log 10\ (1+H) \qquad r = 0.88 \qquad (5)$$

where

N = median vibration nuisance rating (score 0-6)
Leq (63-125Hz) = octave band low frequency noise dB(C)
H = number of heavy commercial vehicles (≥ 3 axles)

A number of studies have found it necessary to include heavy vehicle flow variables in traffic noise nuisance prediction equations (9, 10) particularly under conditions of interrupted flow. In particular Langdon (10) showed that

$$\text{Diss} = 0.089\ L_{10} + 4.31\ \log\ (\%\ \text{HGV}) - 6.56 \qquad r = 0.86$$

where Diss = dissatisfaction with traffic noise (scale 1-7)
L_{10} = 12 hr noise level (dB(A))
% HGV = proportion of heavy vehicles in 12hr flow (> 1500kg)

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It is sometimes argued that the inclusion of heavy vehicles in such prediction equations is because L10 dB(A) scales which attenuate low frequency levels, do not provide an accurate measure of low frequency noise at survey sites. However, Table 2 shows that for this study the low frequency noise scale Leq (40-125Hz) and L10 dB(A) were highly correlated. It would appear therefore, as both Brown (9) and Langdon (10) have speculated, that the heavy vehicle flow parameter acts primarily as a surrogate for noisy vehicles and events. Prediction equations (1) and (3) indicate just how 'noisy' heavy vehicles are for low frequency and broad band noise respectively.

CONCLUSIONS

The main aim of this study was to produce equations relating low frequency traffic noise scales to traffic variables. The equations developed support the hypothesis that medium and heavy commercial vehicles make major contributions to low frequency noise under interrupted flow conditions. However a comparison of the results of this study with others shows a considerable overlap between vibration effects and general traffic noise effects. In this context there is still need for much additional work to provide a clear definition of vibration nuisance particularly if double counting of impacts during strategic environmental evaluation are to be avoided.

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