AN INVESTIGATION OF ROAD TRAFFIC NOISE ON MAIN ROADS IN GREATER LONDON.

A Thesis presented for the Degree of Doctor of Philosophy

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ABSTRACT.

Measurements of road traffic noise were made at 46 locations on single-carriageway hilly main roads, subjected to speed limits, in the Greater London area, where the flow of vehicles was relatively steady. Initially simultaneous recordings were made, as far as possible, at kerbside and 10 m from the kerb but, in the main part of the investigation, observations were made at 18 of the sites, with the microphone in the 10 m position.

It was shown, for a given rate of flow of heavy and light traffic, that L_{10} and L_{50} do not appear to vary with gradients but, because of the relatively high standard deviations, averaging ± 3 dBA, for these quantities, one cannot rule out the possibility of small increases in L_{10} and L_{50} with gradient of up to a maximum of 2 dBA, for the range of values of gradient from zero to about 5 per cent, followed by a decrease for higher values. No definite variation of L_{90} with gradient could be established.

The simultaneous recordings at kerbside and at 10 m from the kerb indicated that the differences between the values of L_{10} for these positions and also between those of L_{50} remained fairly constant; deviations from these differences for some of the sites could in some cases be attributed to their environmental characteristics.

A simple theory was developed for predicting L_{10} and it was found that the measured values of this quantity generally agreed with the theoretical predictions. Parameters expressing the rates of flow of both heavy and light vehicles as single quantities

were established and the variations of the measured values of L_{50} and L_{90} could be well correlated with these parameters.

A subsidiary investigation confirmed that, for a hilly road having a steep slope, the A-weighted indication of the sound level meter correlated better with subjective responses than the B.- and C.-weighted indications.

Measurements with individual vehicles, specially provided for the purpose, did not show any variation of peak sound level with gradient, except for gradients of the order of 10 per cent. Recordings of peak levels from vehicles selected at random at a given site, when the density was low, yielded average values which could be used to predict L_{10} for that site if given the rate of flow of traffic.

CONTENTS

CHAPTER 1.

INTRODUCTION

Road traffic noise is not a new phenomenon. Travelling is rarely a silent occupation, no matter what form of transport is used; the sound of horses' hooves on road surfaces has long been a familiar experience and few persons can deny that the noise from iron-tyred cart wheels on cobbled roads is unpleasant. In more recent years many people have suffered disturbance of sleep by the grinding of tram wheels on rails, especially at corners. However, these noises, characteristic of the past, have affected comparatively few people. During the past two decades there has been a phenomenal increase in the number of motor vehicles together with a sharp rise in the use of heavy diesel lorries. Both cars and lorries are sources of noise but the nuisance they cause is no longer, as in the past, mainly confined to main roads and industrial areas during working hours; it has spread to many once quiet residential districts, often used as short cuts and thus frequently providing annoyance even at night.

Governments and local authorities in most of the industrialised nations have, to varying degrees, expressed concern about the widespread increase in road traffic noise and, in most cases, appropriate action is being taken with a view to its control. In the United Kingdom a Committee formed under the chairmanship of Sir Alan Wilson made a thorough investigation into the causes of different kinds of noise and how these noises can be reduced. Its findings were published in the so-called "Wilson Report" in 1963 (Wilson (1)). One conclusion reached was that, in built-up areas, road traffic noise presented a serious problem. Included in the report was an account of an investigation made jointly by the Building Research Station, the London County Council, and the Central Office of Information, later to be published separately (McKinnell and Hunt (2)). Here it was shown that road traffic noise predominated over all other forms of noise, including those originating from aircraft, industrial premises, constructional work and domestic sources, at 84 per cent of some 400 locations in the London area where investigations were made.

The Wilson report included a number of recommendations for future action, one of which is that research should be done on how traffic noise in hilly districts is affected by the gradient of the road. This has led to the main purpose of the investigation described in this thesis, i.e. to examine how the noise generated by freely flowing traffic in urban main roads, restricted to speed limits, varies with the gradient. The amount of available information in this field is very limited. The intention was to establish a relationship between noise level, overall traffic density, density of heavy vehicles and gradient.

In addition to the main investigation two subsidiary projects were carried out. The first was a study of subjective responses to noises from vehicles travelling both up and down a steep slope and the second was a development of a theoretical method for predicting noise levels in urban main roads with a view to its application to traffic on gradients.

The investigations were conducted under contract with the Transport and Road Research Laboratory of the Department of the Environment.

CHAPTER 2.

CRITERIA FOR NOISE EVALUATION

2.1 GENERAL CONSIDERATIONS

The definition of noise, accepted by the Wilson Committee (1), is "sound which is undesired by the recipient". The report of the Committee accepted that noise may be dangerous to health where "health", according to usage by the World Health Organization, is "a state of complete physical, mental, and social well-being, and not merely an absence of infirmity and disease". There is no doubt that loss of sleep and disturbance of human activity as a result of noise does affect health in an adverse manner and that road traffic is a major contributor to noise.

For a proper investigation of acoustical noise to be made, a suitable criterion for noise level must be established. A major contribution to noise is a high acoustic intensity but this alone may not always give rise to annoyance. Consideration must also be given to the frequency spectrum, time of duration and degree of repetition. Other factors which, by themselves, may not cause annoyance may have to be taken into account. Much will depend on the type of activity carried out by the recipient and also on his state of mind at the time. Thus a particular sound might be regarded as being unobjectionable or even pleasant on one occasion but disturbing on another.

Although the final decision as to what constitutes a noise must be determined by subjective measurements, i.e. of loudness and pitch, a proper investigation of the offending source requires objective measurements of its intensity and an analysis of its frequency spectrum.

2.2 LOUDNESS

Loudness is the effect on the human ear of acoustic intensity and, from the so-called "Weber-Fechner" law, the degree of loudness is proportional to the logarithm of the intensity (Blitz (3)). For a given frequency, the minimum intensity to which the ear responds is called the threshold of audibility (or threshold of hearing) and the maximum intensity which the ear can tolerate without experiencing discomfort is described as the threshold of feeling (or threshold of pain). The ear of a young adult responds to frequencies of up to about 18 kHz but this upper limit reduces with advancing age. The r.m.s. value of the acoustic pressure for a pure tone having a frequency of 1000 Hz at the threshold of audibility is roughly equal to 20×10^{-6} N m^{-2}, corresponding to an intensity of 10^{-12} W m^{-2} for the normal human ear. This is universally accepted, following an I.S.O. meeting in Paris in 1936, as the standard threshold value, and provides the basis for loudness measurements (4). Because of the logarithmic dependence of loudness on intensity, the decibel scale is used for these measurements.

The unit of loudness, accepted by the I.S.O. is the phon (5). The loudness level of any steady sound, simple or complex, is stated numerically in phons as the r.m.s. sound pressure level in dB above 20×10^{-6} N m^{-2} of an equally loud tone having a frequency of 1000 Hz. The subject making the comparison must listen naturally with both ears to the two sounds simultaneously, whilst facing the source of sound in substantially non-reflecting surroundings (e.g. in an anechoic chamber). The phon scale of loudness was evolved from the average response of large numbers of persons subjected to this kind of test.

The variation of loudness, as measured in phons, is illustrated graphically by the "equal loudness contours" shown in Fig.2.1. The threshold of audibility and feeling curves shown in the figure correspond to loudnesses of zero and 120 phons, respectively. The sensitivity of the ear varies with intensity, the difference limen being about 2 phons at lower levels but reducing with increasing level to an upper limit of less than 0.4 phon.

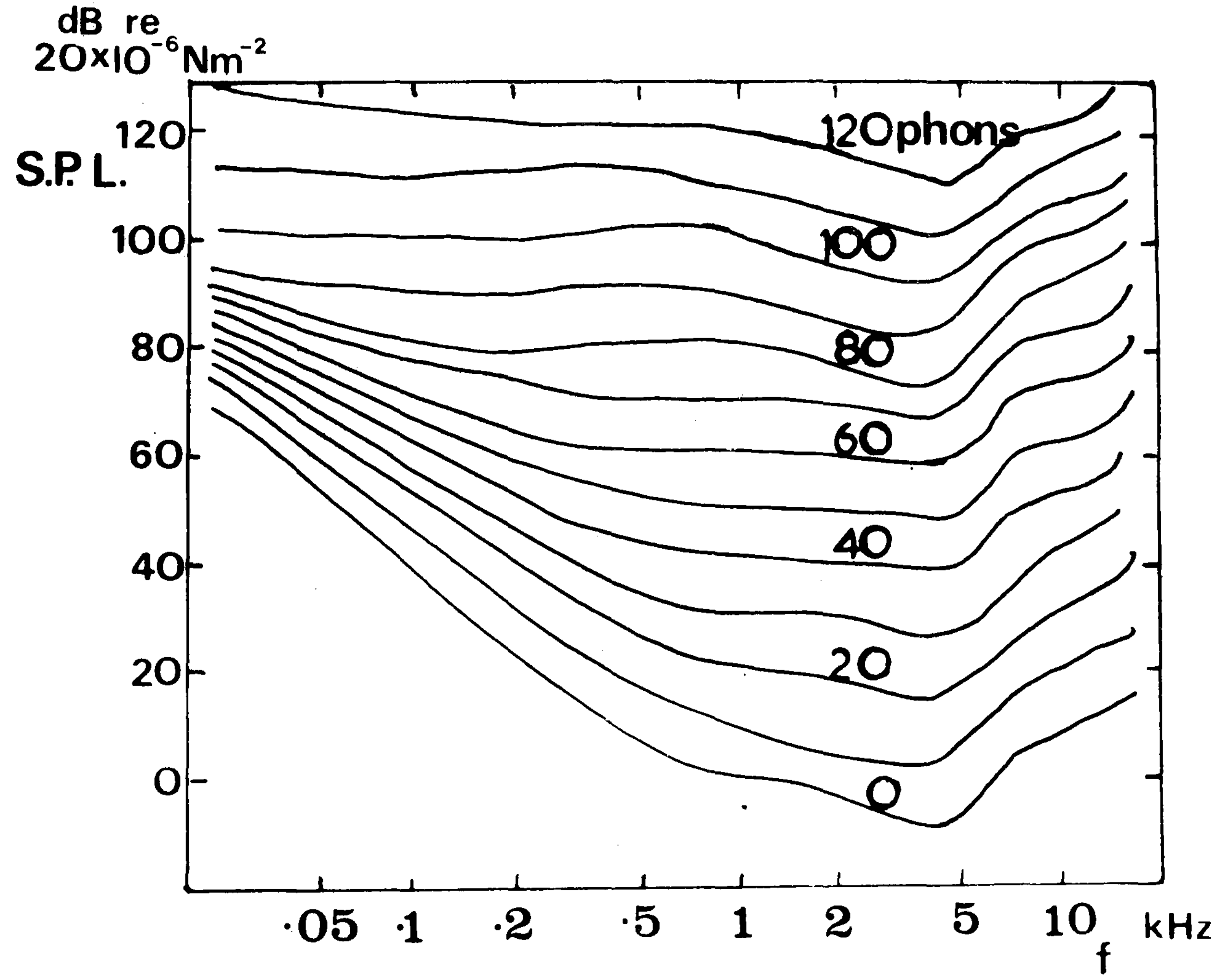
A disadvantage in using the phon scale is that it does not correspond well with relative changes in loudness. A doubling of loudness appears to take place when a given level is increased by 10 phons. Stevens (6) suggested that a fresh unit, the <u>sone</u>, which measures loudness variations more realistically, be adopted. The sone, which was standardised by the I.S.O. in 1947 (7) is defined as follows:

$$\log_{10} S = 0.03(P - 40) \qquad 2.1$$

where S is the number of sones corresponding to P the number of phons, i.e. 1 sone = 40 phons, 2 sones = 50 phons, 4 sones = 60 phons, etc.

2.3. THE SOUND LEVEL METER

Loudness may be measured with an instrument called the sound level meter (8), which is described in Section 8.1.2. The loudness, in phons, of a single pure tone is obtained by switching into the circuit an appropriate weighting network,



S.P.L. = sound pressure level
f = frequency

Fig. 2.1 Typical example of equal loudness contours.

A, B or C (see Fig.8.2) and noting on the meter the registered level in decibels (dB). The A-weighting is intended for use at levels of 40 phons and below, the B-weighting for 70 phons and the C-weighting for 100 phons and above. In practice a reading will generally lie between two of these levels and measurements taken using two appropriate weightings in turn and the mean taken. Thus, if with B weighting the reading is 80 dB (i.e. 80 dBB) and with C weighting it is 82 dB (i.e. 82 dBC), the loudness is taken to be 81 phons.

However, noises rarely comprise single pure tones; they almost invariably contain highly complex sounds. Churcher and King (9) have shown that the method of summation of sounds of different frequencies by the sound level meter is not the same as that by the human ear. In general, the numerical indication in dB of a sound level meter, using the appropriate weighting is lower than the number of phons of actual loudness. It is thus incorrect to use the sound level meter to obtain measurements in phons. However, although this limitation is recognised, it is common practice to quote the sound level meter reading in either dBA, dBB, or dBC, to identify a noise level, e.g. in dBA for road traffic noise.

2.4 THE FREQUENCY DEPENDENCE OF LOUDNESS

More reliable measurements of loudness in either phons or sones are obtainable by means of frequency analyses. A relatively simple method, based on empirical considerations, has been devised by Stevens (10). He obtained equal loudness contours from subjective measurements in a similar manner to that used in deriving the equal loudness contours shown in

Fig. 2.1 but, instead of the frequency being varied in a continuous manner, the sounds were presented to the subjects in octave bands centred at frequencies 31.5, 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz, as provided by standard commercial octave analysers. The subjective tests were conducted for diffuse field listening conditions as opposed to the free-field conditions appertaining to the equal loudness curves.

For a given source of sound, the loudness S, in sones, is measured for each octave band and the total loudness S_T is computed from the following equation:

$$S_T = S_M + 0.3\ (\Sigma S - S_M) \qquad 2.2$$

where S_M is the maximum value of S and ΣS the sum of the loudnesses for all of the bands. Using equation 2.1, S_T can be converted to phons, i.e. "Stevens phons".

The factor 0.3 in equation 2.2 corresponds to the masking effect of S_M over the other values of S. The method can also be used with half and third octave band analyses, for which the corresponding masking factors are 0.20 and 0.15 respectively. Although it is applicable strictly to diffuse listening conditions, Steven's method has been applied to free-field conditions to a reasonably high degree of success.

A more realistic approach to loudness measurements in phons has been made by Zwicker (11). His method is more fundamental than that of Stevens in that the frequency bandwidth for each spectral component depends on the masking effects. If two tones initially have the same intensity and frequency and the frequencies are then slowly changed in opposite directions without change in intensity, no variation in loudness is perceived until the frequency spacing reaches a critical value; this amount of spacing determines the value of the frequency bandwidth. At frequencies higher than 280 Hz the spacings correspond to the bandwidths of standard third-octave filters. The three bands below this value are respectively one octave, one octave and one two-thirds octave in width. Here the loudness is expressed in "Zwicker phons".

Another method, which has been found to be advantageous in measuring noise levels due to jet aeroplanes, was devised by Kryter (12). It is similar to that of Stevens but equal noise rather than equal loudness levels are used. The unit noys is used to represent a noise level characteristic of a given curve. At a frequency of 1000 Hz, the noys and sone scales coincide. The total annoyance N_T is given by the following expression:

$$N_T = N_M + K(\Sigma N - N_M)$$

where N_M is the maximum contribution in noys, ΣN the sum of all the contributions and K a function having a value depending on the frequency bandwidth used, i.e. 0.15, 0.20 and 0.30 for third-, half- and whole-octave bands, respectively, as before. On converting N_T to the decibel scale in the same way in which sones are converted to phons (Equation 2.1), the perceived noise level P', expressed in PNdB, is obtained, as follows:

$$\log_{10} N_T = 0.03\,(P' - 40) \qquad 2.3$$

2.5 LOUDNESS CRITERIA FOR ROAD TRAFFIC NOISE

Although the methods discussed in the previous section, of expressing loudness, have their merits, they are complicated and are inconvenient to use for road traffic noise measurements, which may occupy a considerable time. Robinson and Mills (13) showed that the peak A-weighted sound level from a passing vehicle correlates well with the subjective impression of loudness and the Wilson Committee recommended that the A-weighted sound level meter should be used for all road traffic noise measurements. Although it suffers the disadvantage of being comparatively insensitive to the low frequency components of sound emitted by heavy diesel lorries, it is convenient to use and gives readily reproducible results. A discussion of the relative advantages of the use of A-weighting measurements together with a report of an investigation made by the author into the use of A, B and C-weighting measurements on a hilly road are given later (see Chapter 4).

Measurements of noises emitted by individual passing vehicles do not in themselves constitute road traffic noise evaluations. An effective method must take into account the overall noise experienced at a given site over a long period, e.g. 24 hours. In the London Noise Survey made jointly by the Building Research Station and the London County Council (Parkin et al (14)), noises were recorded for sample two-minute periods, hourly throughout a 24-hour day. Statistical analyses of the dBA sound levels were made and values were obtained of L_{10}, L_{50} and L_{90}, representing respectively the levels exceeded for 10, 50 and 90 per cent of the recording times.

Here L_{50} indicates the average level, L_{10} the peak level, and L_{90} the background level.

Scholes (15) pointed out that L_1 and L_{99}, i.e. the levels exceeded for 1 and 99 per cent, respectively, of the time might be considered as being more realistically representative of the peak and background levels but they are difficult to measure accurately unless the sampling period is long enough to allow for the passage of several hundred vehicles in order to meet the statistical requirements. This may take a considerable time, during which the pattern of the flow of traffic can have changed. However, because the traffic noise level distribution in a given time has been shown to be Gaussian in character, an accurate specification of two points (e.g. L_{10} and L_{90}) on the distribution curve should define all the other points. The sampling time can then be reduced to a minute or two.

Griffiths and Langdon (16) showed how these measurements can be related to subjective responses. They carried out acoustical measurements at 14 sites in London, where they interviewed a representative sample of 1200 residents regarding the degree of annoyance experienced due to road traffic noise. The work resulted in the establishment of the <u>traffic noise index</u>, T.N.I., defined as follows:

$$\text{T.N.I.} = 4\,[(L_{10})_{\text{mean}} - (L_{90})_{\text{mean}}] + (L_{90})_{\text{mean}} - 30 \qquad 2.4$$

where $(L_{10})_{\text{mean}}$ and $(L_{90})_{\text{mean}}$ are the mean values of L_{10} and L_{90} for sampling periods of 100 s in every hour for 24 hours. This takes into account the variability as well as the level of the noise.

A similar survey made by the National Swedish Institute is reported by the Road Research Laboratory (17). It led to the establishment of a noise exposure index L_{eq} based on the energy mean of the noise level, i.e.

$$L_{eq} = K \log (1/100) \Sigma 10^{L_i/K} f_i \qquad 2.5$$

where K is a constant

L_i a median sound level of the i^{th} 5 dBA interval

f_i is the percentage of the time that a sound level is in the i^{th} interval.

Griffiths and Langdon (16) came to the conclusion that $K = 10$ gave the best correlation between L_{eq} and dissatisfaction but not as good as that between TNI and dissatisfaction.

Another index called the noise pollution level L_{NP} was introduced by Robinson (18) to embrace noise produced by a number of sources including road traffic and aircraft, i.e.

$$L_{NP} = L_{eq} + 2.56\sigma \qquad 2.6$$

where the value of L_{eq} is obtained from equation 2.5 by putting $K = 10$ and σ is the standard deviation of the instantaneous sound level considered as a statistical time series over the same specified period. An approximate value of L_{NP} is given by (19)

$$L_{NP} \simeq L_{50} + d + d^2/60 \qquad 2.6(a)$$

where $d = L_{10} - L_{90}$.

Scholes and Sargent (20) suggested that an average value of L_{10} measured out of doors over a period from 0600 to 2400 hours on a weekday should serve as a satisfactory basis of criterion for immediate use although it does not correlate as well with dissatisfaction as T.N.I. This overcomes the difficulty of evaluating L_{90} due to the contribution to the background noise from sources other than road traffic.

Although the limitations of L_{10} as a noise index are fully recognised and will probably be supplanted eventually by a more appropriate criterion, the Noise Advisory Council has now recommended its adoption for rating the disturbance caused by road traffic noise. In the work described in later chapters we shall therefore be primarily concerned with the behaviour of L_{10}.

If relationship can be established between noise levels (e.g. L_{10}, L_{50} and L_{90}) and traffic flow for sites of different characteristics, e.g. gradient, road width, etc., the behaviour of the levels over a given period can be predicted when the pattern of traffic flow is known. This type of prediction can be important in the planning of new roads in relation to existing urban areas, the erection of dwellings in the neighbourhood of roads already in use and the design of new towns.

CHAPTER 3.

SOURCES OF ROAD TRAFFIC NOISE

3.1 LABORATORY MEASUREMENTS OF VEHICLE NOISE

Primary sources of road traffic noise are motor vehicles either in motion or stationary with their engines idling. The nature of the noises emitted from vehicles has been extensively studied and a summary of the results of these studies is given in a report issued by the Road Research Laboratory (17) (now the Transport and Road Research Laboratory), the main points of which are discussed in the remainder of this Section.

Under normal circumstances the engine is the principal source of noise in a motor vehicle. Diesel engines are more troublesome because of abrupt changes in pressure in the cylinders during the working cycles. The noise resulting from this phenomenon masks that originating from the mechanical components, e.g. the pistons and fuel injectors. In petrol engines, however, the pressure variations are less abrupt and thus not so disturbing but the associated mechanical noises may become more significant.

Engine noise can depend on the speed, the load and the cylinder bore. Investigations made by Priede and others at the Institute of Sound and Vibration Research in Southampton show the following relationships between noise level and engine speed

$L = 30 \log_{10} N + K$ for normally aspirated diesel engines 3.1(a)

$L = 40 \log_{10} N + K$ for turbo-charged and two-stroke diesel engines 3.1(b)

$L = 50 \log_{10} N + K$ for petrol engines 3.1(c)

Here L is the sound level in dBA, N the engine speed, and K an undetermined parameter. The effect of load is more important with petrol engines than with diesel engines. A 10 dBA difference has been observed between fully loaded and unloaded conditions for petrol engines, whereas the difference may be less than 3 dBA for diesel engines. Although the size of the cylinder bore has a significant effect on engine noise, the cubic capacity appears to have comparatively little effect. For both petrol and diesel engines the following empirical relation has been found to hold:

$$L = 50 \log B + K \qquad 3.2$$

where L is the level in dBA, B the bore diameter and K an undetermined parameter.

The spectra of engine resonances are characteristic of resonances in the cavities and structures, e.g. high noise levels in the 1 to 3 kHz range of frequencies due to high sound pressure levels as characterised by diesel knock. This phenomenon, at present, has received little attention.

Engine noise may be cut down by suitable design of the engine and reductions of up to 10 dBA may be possible in this way but it is more usual, for economical reasons, to design the enclosure of the power unit for maximum noise reduction.

Associated with engine noises are the sounds emitted from the inlet and exhaust, the fan, and, for two-stroke engines, the scavenger blower. Although the inlet and exhaust noises are reduced by the use of silencers, they are still significant in their effects. Priede obtained the following relationship between sound level in dBA and engine speed for this phenomenon, i.e.:

$$L = 45 \log_{10} N + K \qquad 3.3$$

where, again, K is an undetermined constant. Changing from conditions of no engine load to full load has been shown to produce a considerable increase in exhaust noise and, for heavy diesel vehicles, it may be as high as 20 dBA.

Cooling fans and scavenger blowers, both controlled by the engine, produce noise outputs which also vary in the manner shown by the above equations.

The nature of the sound radiated from the transmission system is not well understood but the resulting noise is recognised to be of importance by the need to sound-proof the gear box. Aerodynamic noise, although of possible annoyance to passengers, does not seem to be of any consequence to persons outside the vehicle.

Road surfaces and tyre noise are dependent on the speed of the vehicle, the type of tyre tread, the nature of the road surface and whether or not the surface is wet. Brake noise and noise from horns, although annoying, do not occur for long enough periods to make any significant contribution to the overall noise level.

Other causes of vehicle noise are the vibrations of the vehicle structure and of the pay load, including empty crates. They may, on occasion, be very troublesome but because their characteristics vary considerably between different vehicles it is not easy to conduct an investigation into their nature.

3.2 MEASUREMENTS OF THE NOISE FROM VEHICLES IN MOTION

From the point of view of road traffic noise measurements a vehicle must be considered in relation to its surroundings and the overall source of sound, i.e. the vehicle itself and the road surface in the immediate neighbourhood. The exact locations of the individual sources in a vehicle and how the radiation from these sources is scattered by the road surface and the body of the vehicle itself are virtually undeterminable. It will therefore be assumed that each vehicle on the road is a hemispherical radiator having its centre on the road surface.

Measurements of the noise characteristics of individual vehicles must be conducted independently of any surroundings other than the road surface in order to obtain conditions of hemispherical radiation. A site used for this purpose by the Transport and Road Research Laboratory at Crowthorne consists of a circular area surfaced with smooth asphalt having a diameter of 275 m on which a layout is marked in accordance with I.S.O. Rec. 362, 1964 (see Fig. 3.1). This ensures

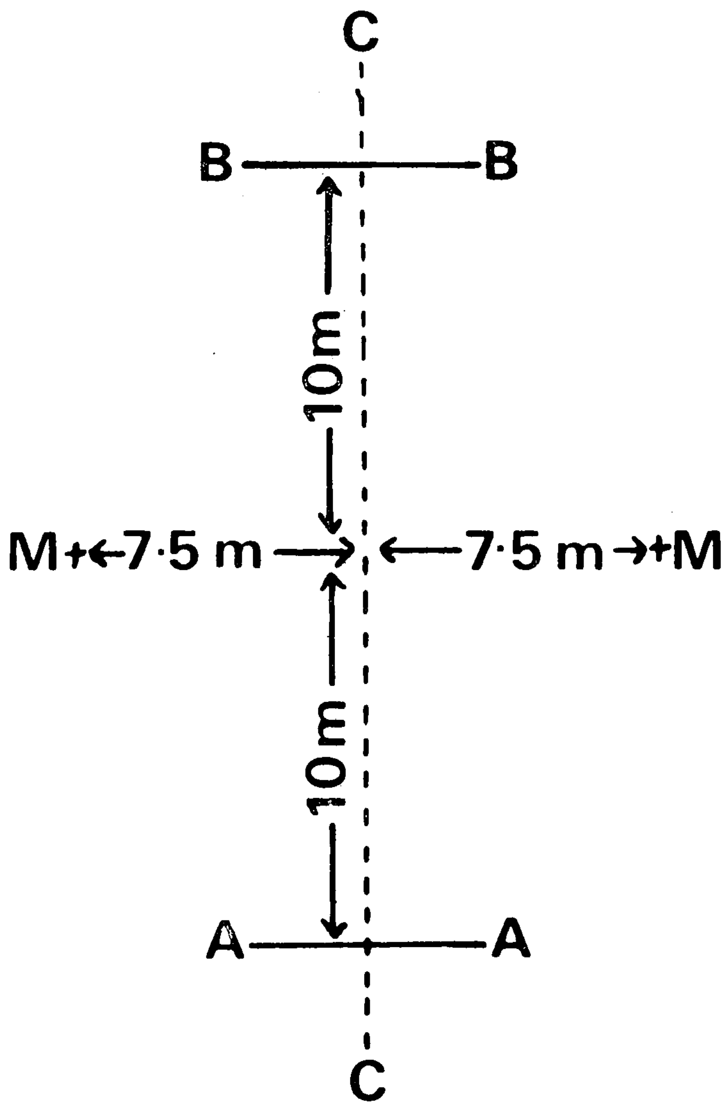


Fig. 3.1 Layout of site for measurements of noises from individual vehicles, in accordance with ISO Rec. 362, 1964. (M = position of microphone.)

easy comparison with investigations made elsewhere. Two microphones mounted on tripods to lie 1.2 m above the road surface level are located on both sides of the vehicle path, as shown. Tests may be made under specified conditions such as steady speed, steady acceleration in a particular gear, coasting with the engine switched off, and stationary with the engine idling. For example, Ross (21) showed by this method that, for light vehicles moving at steady speeds v km hr^{-1} in top gear between the lines AA and BB on a dry surface, the level L in dBA at a point 7.5 m from the centre vehicle line is given by

$$L = 33.6 \log_{10} v + 12.6 \qquad 3.4$$

with a standard error of 2.6 dBA.

Thus for a car travelling at 45 km hr^{-1}, L = 66 dBA at a distance of 7.5 m and 60 dBA at 15 m. No information regarding heavy vehicles was given. Harland (44) found, with heavy vehicles moving at steady speeds of less than 60 km hr^{-1}, that sound levels increased by 9 dBA per doubling of speed.

Stephenson and Vulkan (22) performed vehicle sound level measurements at the roadside, conforming as near as possible to the conditions described above. In this way they could obtain measurements on a large number of different types of vehicles and thus to observe the characteristics of several vehicles of any one type; the number of measurements was 1100. The chosen site was a road crossing Blackheath in London, which met the following requirements:

(i) Level straight road.

(ii) No buildings or trees within 100 yd (91 m).

(iii) Traffic moving freely but subjected to a 30 m.p.h. (48 km hr^{-1}) speed limit.

(iv) No road junctions, traffic lights, or pedestrian crossings within 200 yd (183 m).

(v) Traffic density less than 120 vehicles per hour, which enabled measurements of individual vehicles to be made without being affected by noise from other vehicles.

(vi) Low background noise, i.e. below 55 dBA.

Two microphones were located on each side, both 7.5 m from the centre line of the road which was 7.2 m wide. The distance from the microphone was virtually the same for vehicles moving in both directions since they tended to be driven near the crown of the road, because of the low traffic density. Noise levels were virtually the same as observed from both sides of the road. The weather was clear and dry and winds were only slight. Readings of the sound level meter were taken only for vehicles travelling at steady speeds. Their results are summarised in Table 3.1.

Lewis (23), investigating noise levels from both light and heavy vehicles flowing freely at different speeds between 50 and 126 km hr^{-1} observed a difference of about 9.5 dBA between the two classes at the lower speeds. Extrapolating to 45 Km hr^{-1} should account for a difference of about 10 dBA. For light vehicles an increase in 10 dBA was observed on doubling the speed but for heavy vehicles the increase in level was only about 6.5 dBA.

Galloway, Clarke and Kerrick (24) concluded that the two main components of vehicle noise are the engine-exhaust system and the tyre-roadway interaction. For cars these components are equal for steady speeds, but with acceleration the engine-exhaust component increases. The noise from lorries is

TABLE 3.1

INDIVIDUAL VEHICLE NOISE - BLACKHEATH

(After Stephenson and Vulkan (22).)

Steady speed 25-30 m.p.h. (40-48 km hr^{-1}) at 25 ft (7.5m).

VEHICLE TYPE	MEAN LEVEL	TOTAL NO. OF VEHICLES	STANDARD DEVIATION	NOISE LEVEL RANGE FOR 80% OF VEHICLES
	dBA		dBA	dBA
Light car (under 1100 c.c.)	70	211	2.5	67-75
Medium car (1100-1600 c.c.)	71	252	2.6	67-75
Heavy car (over 1600 c.c.)	72	149	2.9	68-77
Light commercial (four wheeled)	73	110	2.4	69-77
Heavy commercial	81	370	3.3	76-86
L.T. buses	83	24	1.9	80-85
Motor cycles	77	53	3.9	72-83

difficult to predict because of considerable variations of conditions between different vehicles. Although the surface area of contact between road surface and tyres is much greater than for cars, the contribution from the engine-exhaust system is more prominent than from the tyre-road surface interaction. Noise levels from heavy diesel vehicles are typically from 10 to 15 dBA higher than those from passenger cars. It should be noted that in the U.S.A. where these findings were made, lorries are generally much larger and noisier than in the United Kingdom.

For cars moving at steady speeds on smooth road surfaces they predicted that the level in dBA for a distance of d ft from the observer is given by

$$\begin{aligned} L &= 16 - 10 \log_{10} (d/50)^2 + 30 \log_{10} v \\ &= 50 - 20 \log_{10} d + 30 \log_{10} v \end{aligned} \qquad 3.5$$

where v is the speed in m.p.h. For rough road surfaces the level may be increased by up to 5 dBA. For maximum acceleration the increase in level may be as high as 6 dBA, as a result of higher noise levels from the engine.

They did not find any significant increase in noise level from heavy diesel vehicles with speed. This was attributed to these vehicles tending to change gear more frequently and run at constant engine speed.

Galloway et al also investigated the noise spectra from cars and heavy diesel vehicles. Their average octave band analyses over the range from 63 to 8000 Hz taken for large numbers of vehicles at 50 ft. (15 m) distance are shown in Fig.3.2. In both cases noise levels are highest at low frequencies with pronounced low frequency peaks for heavy diesel lorries. The respective levels for the heavy and light vehicles were 82 dBA and 67 dBA. The standard deviations in each case were approximately 2.5 dBA. Comparing these results from those obtained by Lewis and by Stephenson and Vulkan at Blackheath and allowing for a doubling of distance (i.e. 15 m instead of 7.5m) it is seen that although the noise levels for light vehicles are of the same order of magnitude the American heavy vehicles are about 5 or 6 dBA noisier than their British counterparts.

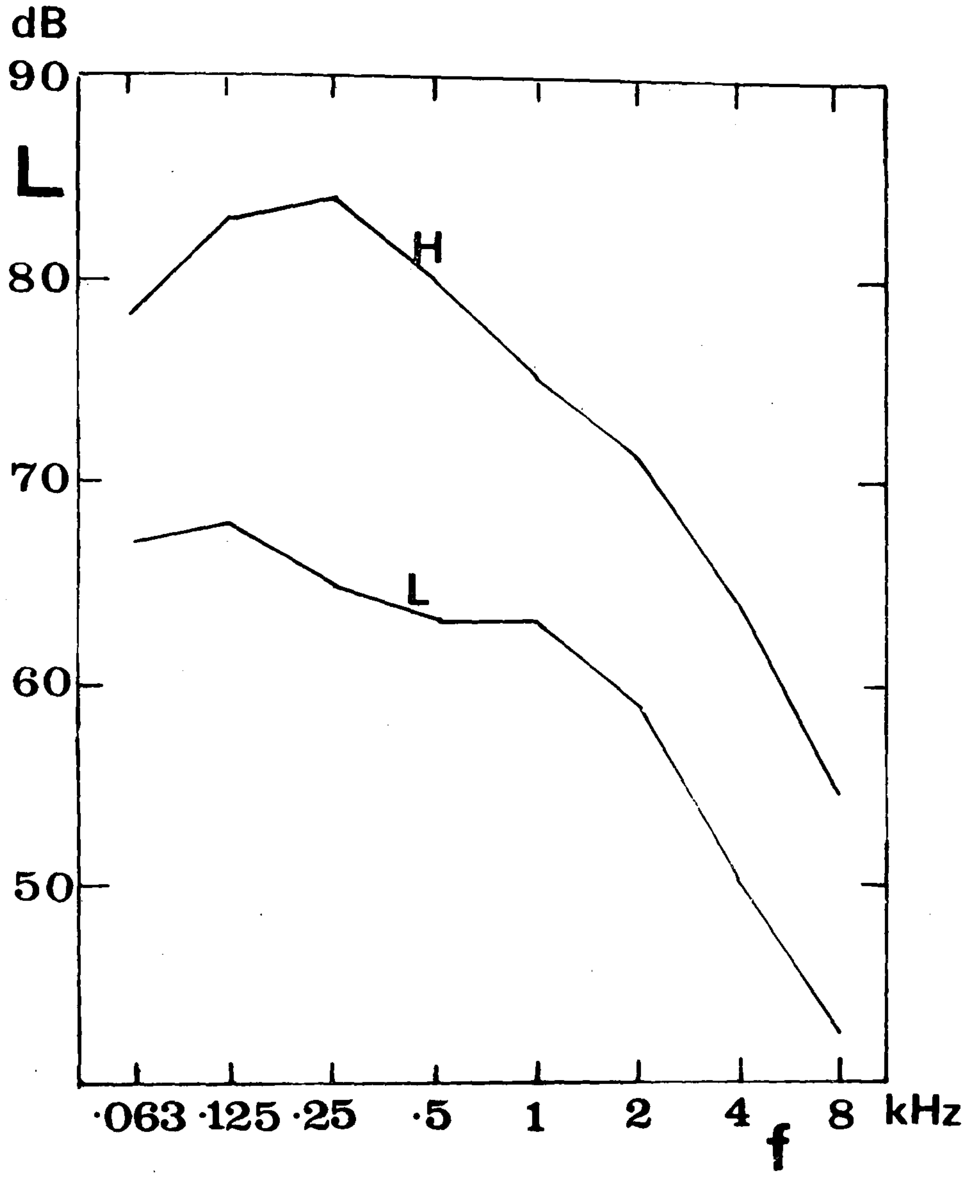


Fig. 3.2 Mean octave band spectra for heavy (H) and light (L) vehicles, (after Galloway et al (24)).

CHAPTER 4

THE SUBJECTIVE MEASUREMENT OF VEHICLE NOISE

4.1 GENERAL CONSIDERATIONS

One of the recommendations of the Wilson Report (1) was that traffic noise measurements should be made with the sound level meter (see Section 8.1.2) switched to A-weighting. This recommendation was made as a result of investigations made by the National Physical Laboratory and the Motor Industries Research Association.

In an investigation made by the National Physical Laboratory (Robinson, Copeland and Rennie (26)) a jury of 19 listeners were assembled with a view to correlating their subjective responses with objective measurements, with sound level meters switched to both A- and B-weightings, to noises from individual vehicles in motion. The subjects were seated side by side, 1 m apart, along a line parallel to and at a distance of 7 m from the centre line of the southbound carriageway of the A23 London to Brighton road where the gradient was 7 per cent uphill. The subjective ratings were given in accordance with a 6-point scale shown in Table 4.1. The mean numerical value of the subjective response of the subjects for each passing vehicle was compared with the measured peak sound levels for both A- and B-weighting. Graphs were plotted separately of mean subjective response against measured sound levels for both private and commercial vehicles and regression lines obtained in each case. The corresponding correlation coefficients were determined.

TABLE 4.1

SUBJECTIVE NOISE RATING USED BY ROBINSON, COPELAND AND RENNIE (27)

A	B	C	D	E	F
-	Quiet	Acceptable	Noisy	Very noisy	-
0	2	4	6	8	10

Their results are shown in Table 4.2. Also shown in the table, by way of comparison are earlier results of similar work done in Switzerland (27) and the U.S.A. (28). The table shows that A-weighting seems to provide a better correlation with subjective measurements than B-weighting, although for commercial vehicles the correlation coefficients are comparatively low in both cases.

In the American paper (28) referred to by Robinson, Copeland and Rennie, a correlation coefficient for C-weighting of noise from moving commercial vehicles was found to be as low as 0.52.

Further work was carried out by Robinson and Mills (13) at the proving ground of the Motor Industries Research Association at Nuneaton under conditions specified by ISO Rec. 419, 1966 (29) with a jury numbering 57. Vehicles of various types were driven past the observers to provide a total of 150 different driving conditions but no significant improvement in the correlation between the subjective measurements and A-weighted measured levels could be obtained for diesel vehicles. Mills (30) showed a slightly better correlation for loudness, measured in Zwicker phons, than for A-weighting but measurements in Stevens phons showed a correlation of the same order as for B-weighting.

Although the spectrum of noise from diesel vehicles has a larger component of lower frequencies than that from petrol driven vehicles, C-weighting measurements have been shown to produce a poor correlation with subjective measurements for diesel vehicles, Hillquist (31) using a sample of 100 diesel

TABLE 4.2

CORRELATIONS BETWEEN SUBJECTIVE RESPONSES AND BOTH A AND B WEIGHTING MEASUREMENTS, OBTAINED BY ROBINSON, COPELAND AND RENNIE (27) IN COMPARISON WITH SIMILAR RESULTS OBTAINED IN SWITZERLAND (28) AND THE U.S.A. (29).

SOURCE	TYPE OF VEHICLE	VEHICLE CONDITION	CORRELATION COEFFICIENT WEIGHTING A	CORRELATION COEFFICIENT WEIGHTING B	MAXIMUM DEVIATION dB WEIGHTING A +	MAXIMUM DEVIATION dB WEIGHTING A -	MAXIMUM DEVIATION dB WEIGHTING B +	MAXIMUM DEVIATION dB WEIGHTING B -
Robinson	Private Cars	Moving	0.94	0.79	4.5	5.0	6.1	5.4
et al	Comm.Vehicles	Moving	0.84	0.74	5.2	4.0	7.1	7.1
Swiss	Mixed	Moving	0.95	0.88	4.4	6.0	5.8	5.6
Paper	Mixed	Stat'y	0.95	0.91	6.0	5.2	3.8	6.0
U.S.A. Paper	Commercial Vehicles	Moving (Recorded)	0.83	0.75	3.3	2.0	-	-

lorries, obtained a correlation with subjective measurements of 0.95 for A-weighting but only 0.86 for C-weighting.

4.2 SUBJECTIVE MEASUREMENTS ON A STEEP GRADIENT

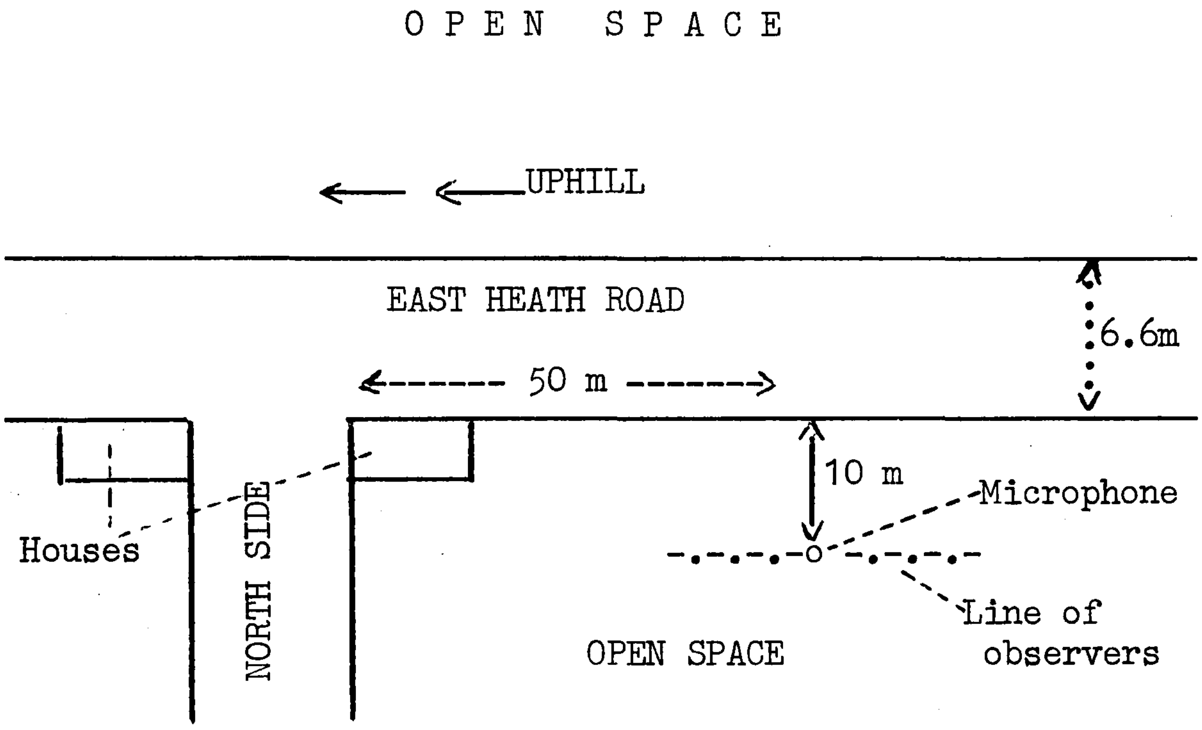
Although the investigations of subjective responses to vehicle noises made by Robinson et al (26) were made where the road had a gradient of 7 per cent, only uphill traffic was taken into account and the jury was positioned close to the roadside. In the investigations of road traffic noise, described in later chapters, measurements taken only for single carriageways carrying two-way traffic and recordings of noise were made with the microphone placed 10 m back from the kerb. It was thus considered desirable to investigate subjective responses under these latter conditions and to take into account both light and heavy vehicles proceeding both uphill and downhill.

The site chosen for the present investigation was in East Heath Road, Hampstead, London, N.W.3 (see Figure 4.1). This was one of the sites (No.10) used for the objective measurements described in Chapter 8. The road is 6.6 m wide, has a gradient of 11 per cent, is bounded both sides with open grassland, is straight for about 150 m and free from obstruction. Furthermore, at the time of the experiment, 14.30 to 16.00 hrs on Wednesday 20 October 1971, the traffic density was sufficiently low to enable the jury to assess the noise levels from individual passing vehicles without interference from other vehicles. Also, extraneous sources of noise were absent for most of the time. The weather was dry and winds were light and variable. The road surface, made of stoned

FIG. 4.1

SITE AT EAST HEATH ROAD USED FOR SUBJECTIVE MEASUREMENTS

14.30 TO 16.00 HRS ON WEDNESDAY, 20 OCTOBER 1971



asphalt, was also dry.

Measurements at noise level from individual vehicles were made with a precision sound level meter (B and K type 2206) mounted on a tripod and connected to a tape recorder (Uher Report 4000 L). The microphone of the sound level meter was covered with a wind-shield and located with its diaphragm in a vertical plane parallel to the line of the road, at a height of 1.2 m from ground level and distance 10 m from the side of the road where traffic proceeded uphill. This was the arrangement used for the objective measurements forming part of the main investigation, described in Chapter 8.

The jury consisted of 18 persons aged between 18 and 22 (i.e. students of Brunel University) and 2 persons aged 49 and 50, respectively. They were located 1 m apart along a line 10 m parallel to the road, equally spaced on both sides of the microphone but separated from it by at least 2 m.

34 vehicles proceeding both uphill and downhill were considered for objective measurement and subjective judgment. They consisted of 16 private cars and 18 commercial vehicles, the latter consisting of 8 heavy diesel lorries having three or more axles. Approximately equal numbers of each class of vehicle travelled in opposite directions.

The sound level meter was switched to C-weighting and recordings were made at both the start and finish of the experiment of a signal of 94 dB at a frequency of 1000 Hz and duration 1 minute provided by the sound level calibrator (B and K type 4230). The signal was also applied halfway through the test.

During the passage of each specified vehicle, the noise was recorded and, at the same time, each subject recorded his response on a Noise Rating Form, originally designed by the Transport and Road Research Laboratory. The form (see Table 4.3) allows for each noise to be rated on a seven point scale.

After the tests were completed the recordings were played back and the output of the tape recorder fed to a Level Recorder (B and K 3305) through a weighting network, where A and B weightings were required, provided by a microphone amplifier (B and K Audio Spectrometer, type 2206).
The calibration of the Level Recorder was effected by means of the 94 dB steady signal of 1000 Hz frequency, as provided by the calibration at the time of recording. In this way the peak noise levels for each tested vehicle was obtained. The subjective levels were determined by calculating the mean subjective response for each vehicle from numerical values, i.e. 0, 2, 4, 6, 8, 10 and 12 corresponding respectively to each rating.

Table 4.4 illustrates the measured sound levels in dBA, dBB and dBC together with the mean subjective responses for each vehicle. Figures 4.2, 4.3 and 4.4 show plots of objective measurements of peak noise levels against subjective responses, as observed from Table 4.4, for A, B and C weightings respectively. Regression lines are shown in each case and correlation coefficients and maximum deviations calculated. The results are shown in Table 4.5. It is seen that A-weighting measurements provide the best correlation with subjective measurements.

TABLE 4.3

EXAMPLE OF COMPLETED NOISE RATING FORM.

NOISE RATING FORM

Please print the following details

Name ....A.NYONE............................ (Mr, ~~Mrs or Miss~~)

Age ....32........... Occupation ..TECHNICIAN........

Country in which you now live ......U.K..............................

Please give your opinion of each test after the vehicle has passed by placing a tick in the appropriate category column of the rating table below. If you consider that any test falls between two adjacent categories you should tick both columns. There are unlabelled columns at both sides of the table. You should use one of these columns for any noise that you consider to be outside the range of labelled columns.

		Very Quiet	Quiet	Moderate	Noisy	Very Noisy	
Test 1				✓			
Test 2					✓		
Test 3					✓		
Test 4			✓				
Test 5					✓		

		Very Quiet	Quiet	Moderate	Noisy	Very Noisy	
Test 6					✓		
Test 7				✓			
Test 8					✓		
Test 9						✓	
Test 10			✓				

		Very Quiet	Quiet	Moderate	Noisy	Very Noisy	
Test 11					✓		
Test 12							✓
Test 13				✓			
Test 14					✓		
Test 15						✓	

		Very Quiet	Quiet	Moderate	Noisy	Very Noisy	
Test 16		✓					
Test 17					✓		
Test 18				✓			
Test 19						✓	
Test 20						✓	

TABLE 4.4.

SOUND LEVEL MEASUREMENTS AND MEAN SUBJECTIVE RESPONSES

FOR INDIVIDUAL VEHICLES. (E.HEATH ROAD 20.10.71.)

TEST NO.	SOUND LEVEL MEASUREMENTS			MEAN SUBJECTIVE RESPONSES.
	dBA	dBB	dBC	
1	77	85	93	7.8
2	64	89	90	4.8
3	80	90	94	7.3
4	68	83	92	5.6
5	80	89	93	8.6
6	72	84	92	6.1
7	70	83	92	5.5
8	66	83	90	6.8
9	78	88	92	8.4
10	82	92	94	9.0
11	66	76	90	5.8
12	62	87	90	4.6
13	76	90	93	7.2
14	70	84	92	8.1
15	67	87	94	5.9
16	76	90	90	4.7
17	76	86	91	7.5
18	82	93	94	9.2
19	76	90	93	6.8
20	74	88	93	8.9
21	83	94	95	10.1
22	73	82	92	6.8
23	66	86	89	7.5
24	70	83	90	6.5
25	68	86	93	5.1
26	76	88	94	7.6
27	77	89	93	8.9
28	64	81	92	4.2
29	74	87	94	7.5
30	73	87	92	5.1
31	84	91	95	9.3
32	79	89	93	8.4
33	73	89	94	6.3
34	68	80	89	5.3

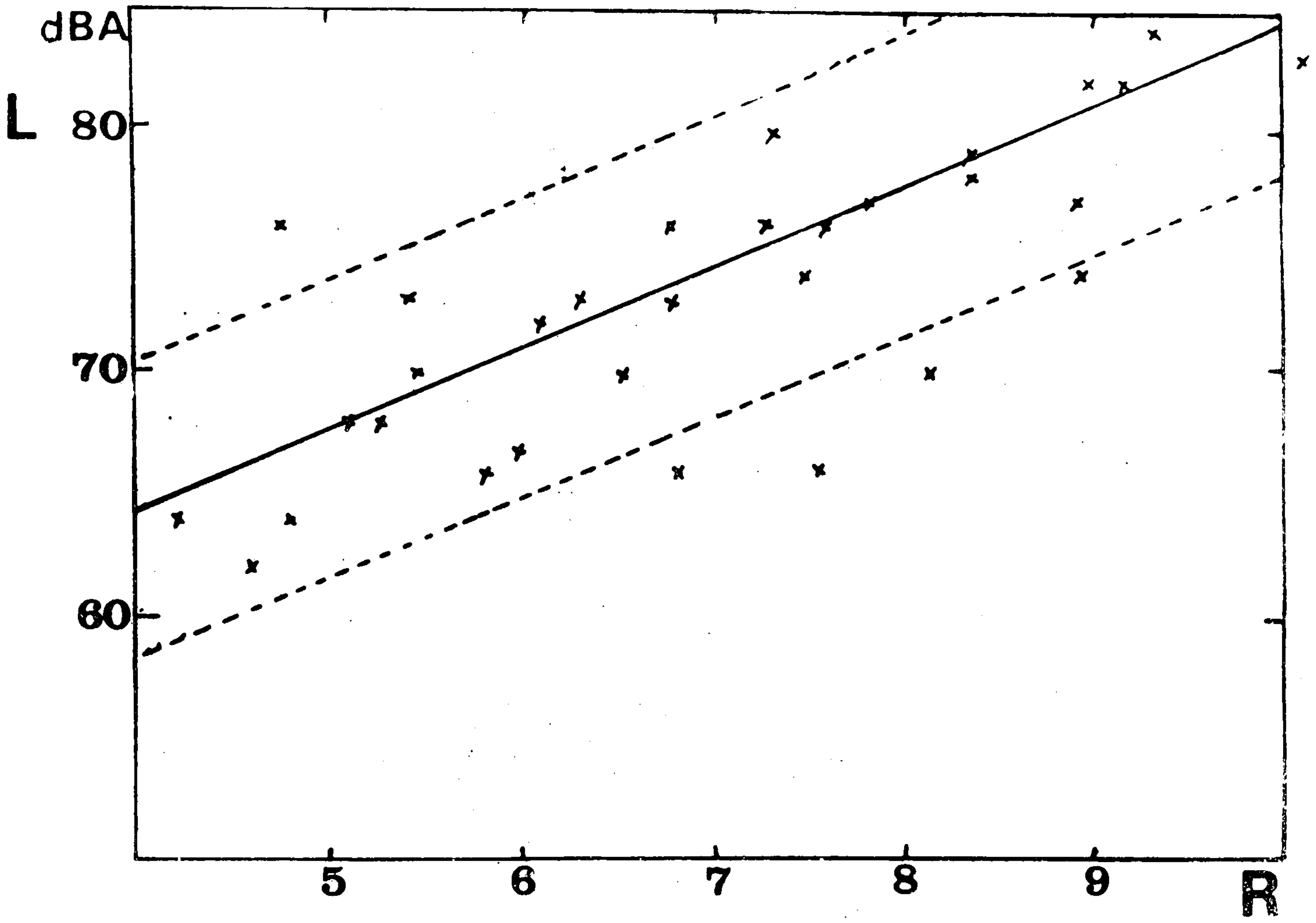


Fig. 4.2 Plot of peak noise levels L (dBA) against mean subjective responses R. (East Heath Road).

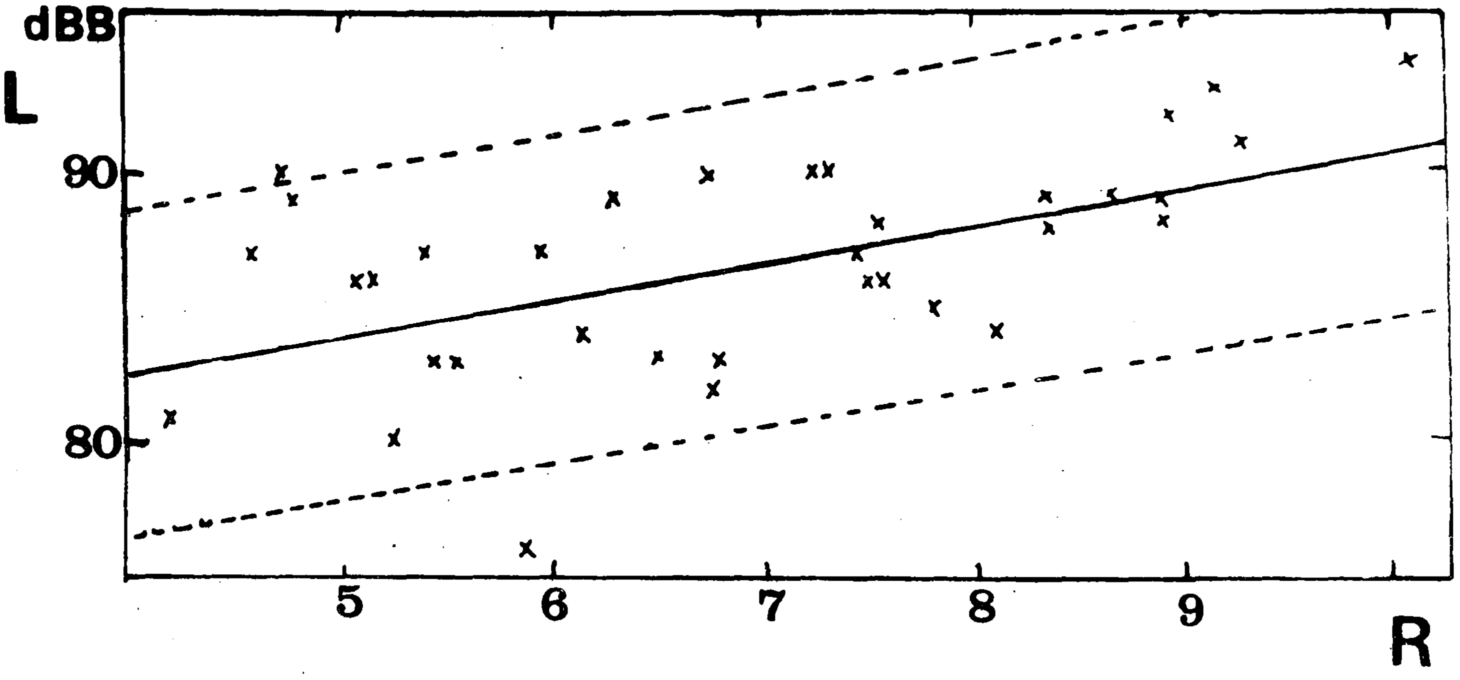


Fig. 4.3 Plot of peak noise levels L (dBB) against mean subjective responses R.(East Heath Road).

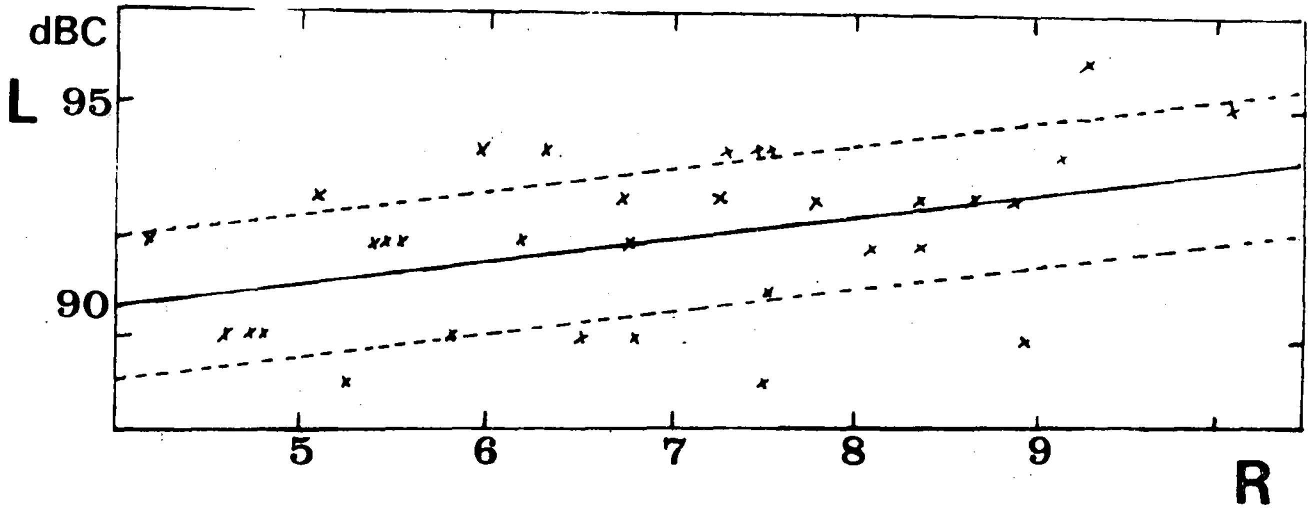


Fig. 4.4 Plot of peak noise levels L (dBC) against mean subjective responses R. (East Heath Road).

TABLE 4.5

CORRELATIONS BETWEEN SUBJECTIVE RESPONSES AND A, B AND C WEIGHTING MEASUREMENTS OBTAINED AT EAST HEATH ROAD.

WEIGHTING	CORRELATION COEFFICIENT	MAXIMUM DEVIATIONS			
		dB		Subj. Resp.	
		+	-	+	-
A	0.79	9.0	10.0	3.0	2.7
B	0.54	6.4	9.2	5.7	4.5
C	0.47	2.7	3.4	6.5	5.2

The correlation coefficients do not appear to be as high as those obtained by previous workers. This is almost certainly due to the relatively small sample used. However, the results obtained for a road having a steep gradient appear to follow the same trend as those for level roads and for less steep gradients.

CHAPTER 5

THE PRESENT STATE OF ROAD TRAFFIC NOISE MEASUREMENTS IN THE UNITED KINGDOM

5.1 GENERAL CONSIDERATIONS

Large scale surveys of road traffic noise have been made in a number of countries including the U.S.A. (24), France (31) and W. Germany (32, 33). We shall restrict our discussion to the work done in the United Kingdom. The reason for this is that the pattern of traffic and methods of driving on both urban and rural roads is somewhat different ~~from that~~ in this country. For example, heavy vehicles in Great Britain are smaller and tend to travel more slowly than in other countries and private vehicles are generally driven with more consideration here than abroad. Also, ownership is more universal here than on the Continent, and in the U.S.A. private vehicles are generally larger and more powerful than here.

5.2 MEASUREMENTS IN URBAN ROADS

To determine the road traffic noise climate objectively at a particular location, a knowledge is required of the mean values of L_{10}, L_{50} and L_{90} over a 24-hour period on a weekday or, at least, the mean value of L_{10} over an 18-hour period on a weekday (see Section 2.5). However, it may be possible to predict the values of thse parameters if their dependence on other factors can be determined. These other factors are:

(a) traffic density

(b) traffic composition (i.e. relative numbers of light and heavy vehicles).

(c) mean speed of the traffic
(d) gradient of the road
(e) width of the road
(f) nature and conditions of the road surface
(g) weather conditions
(h) nature of the traffic flow
(j) nature of the physical surroundings.

Sound level recordings may be made over a time period long enough for a sufficient number of vehicles to flow in order to apply an accurate statistical analysis. The accuracy of the statistical analyses is improved still further if measurements are taken at a large number of sites. This will tend to even out variations of (c) the mean speed of the traffic, (e) the width of the road, (f) the nature and conditions of the road surface, (h) the nature of the traffic flow and (j) the nature of the physical surroundings. In urban districts the surfaces of main roads are almost invariably made of stoned asphalt and, during dry weather, road surface variations are negligible. During wet weather there may be a considerable increase in the noise level due to tyre and road surface noise. ~~and~~ Fog gives rise to attenuation and wind will have the effect of deflecting sound waves. Measurements should thus be confined to periods of dry clear weather when the winds are light.

Variations caused by (h) the nature of the traffic flow may be reduced by confining measurements to locations where the flow is steady and subjected to a speed limit of 30 m.p.h., (48 km hr^{-1}). Steady flow conditions are generally observed if there is an absence of traffic hazards such as parked vehicles, neighbouring intersections, pedestrian crossings and traffic signals as well as unpredictable events, e.g. accidents, and predictable events, e.g. rush-hour congestion. Variations due to (j) the nature of the physical surroundings can be reduced by avoiding locations, especially narrow streets, where tall buildings and walls are likely to reflect traffic noise. Furthermore, it is preferable to avoid very wide roads, including dual carriageways, and very narrow roads in order to reduce fluctuations due to (e) the width of the road. When the dependences of noise levels on traffic density, traffic composition, and gradient are determined, it is a relatively simple matter to correct for road width and the effects of reflections at flanking buildings and walls.

In most previous investigations (e.g. Stephenson and Vulkan (22)) and also in the work to be described later, measurements were made only under conditions of steady flow. Experience of traffic on most urban roads, excluding motorways and trunk roads, shows that the average speed is fairly consistent at 30 m.p.h. (48 km hr^{-1}) under conditions of free flow and it is customary for traffic to move only in two lanes, even when the road is wide enough to provide four lanes. Additional lanes tend to be used only by vehicles when overtaking, an event which is comparatively rare at a given location during a recording period of, say, 15 minutes. Furthermore, the number of available lanes is often reduced by the presence or anticipation of parked cars.

Stephenson and Vulkan (22, 34) made kerbside measurements at some 140 sites on level urban roads where the traffic was flowing freely at speeds between 20 m.p.h. (32 km hr^{-1}) and

30 m.p.h. (48 km hr^{-1}) in the London area. Noise level recordings were made over 15 minute periods and from statistical analyses of these recordings, values of L_{50} and L_{10} were calculated. Figures 5.1 and 5.2 illustrate the variations of their values of L_{50} and L_{10} respectively, with traffic density. They show that the level rises rapidly, at first, with increasing traffic density and then more gradually at a steady rate, for traffic densities of greater than about 1200 vehicles per hour, for which the increase becomes less than 3 dBA for doubling of traffic volume. Approximate increases of 3 dBA in both L_{10} and L_{50} are seen to take place for doubling the densities of heavy traffic. This appears to be consistent with the increased level when the traffic volume is doubled at low densities of heavy vehicles.

The measurements made by Stephenson and Vulkan at kerbside may be open to objection in that at such a close distance to the traffic, vehicle rather than traffic noise may be measured. The objection may be especially valid for the determination of L_{50} and for L_{10} with ~~heavy traffic~~ high densities, for which the traffic should act as a line rather than a point source. In the former case, attenuation takes place at the rate of 3 dB per doubling of distance and, in the latter case, at the rate of 6 dB per doubling of distance. This is important when calculating values of L_{10} and L_{50} at locations removed from the roadside. In the investigation forming the major part of this thesis, this difficulty was avoided by conducting measurements at points 10 m back from the kerb.

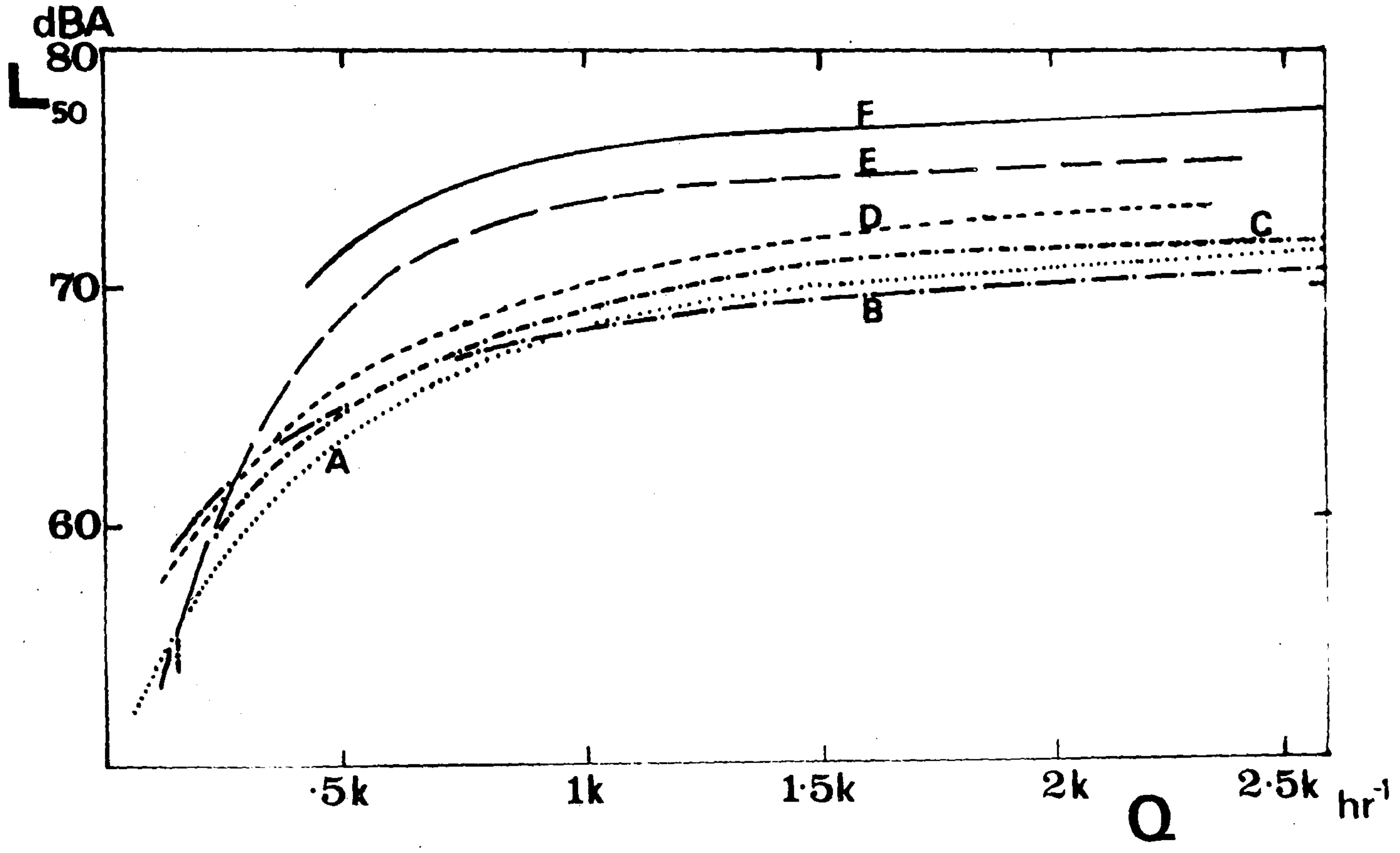


Fig. 5.1 Variation of L_{50}, at kerbside, with rate of flow Q for different percentages of heavy vehicles, as indicated below (after Stephenson and Vulkan (22)).

A Under 16 per cent.
B 16 to 20 per cent.
C 20 to 25 per cent.
D 25 to 33 per cent.
E 33 to 50 per cent.
F Over 50 per cent.

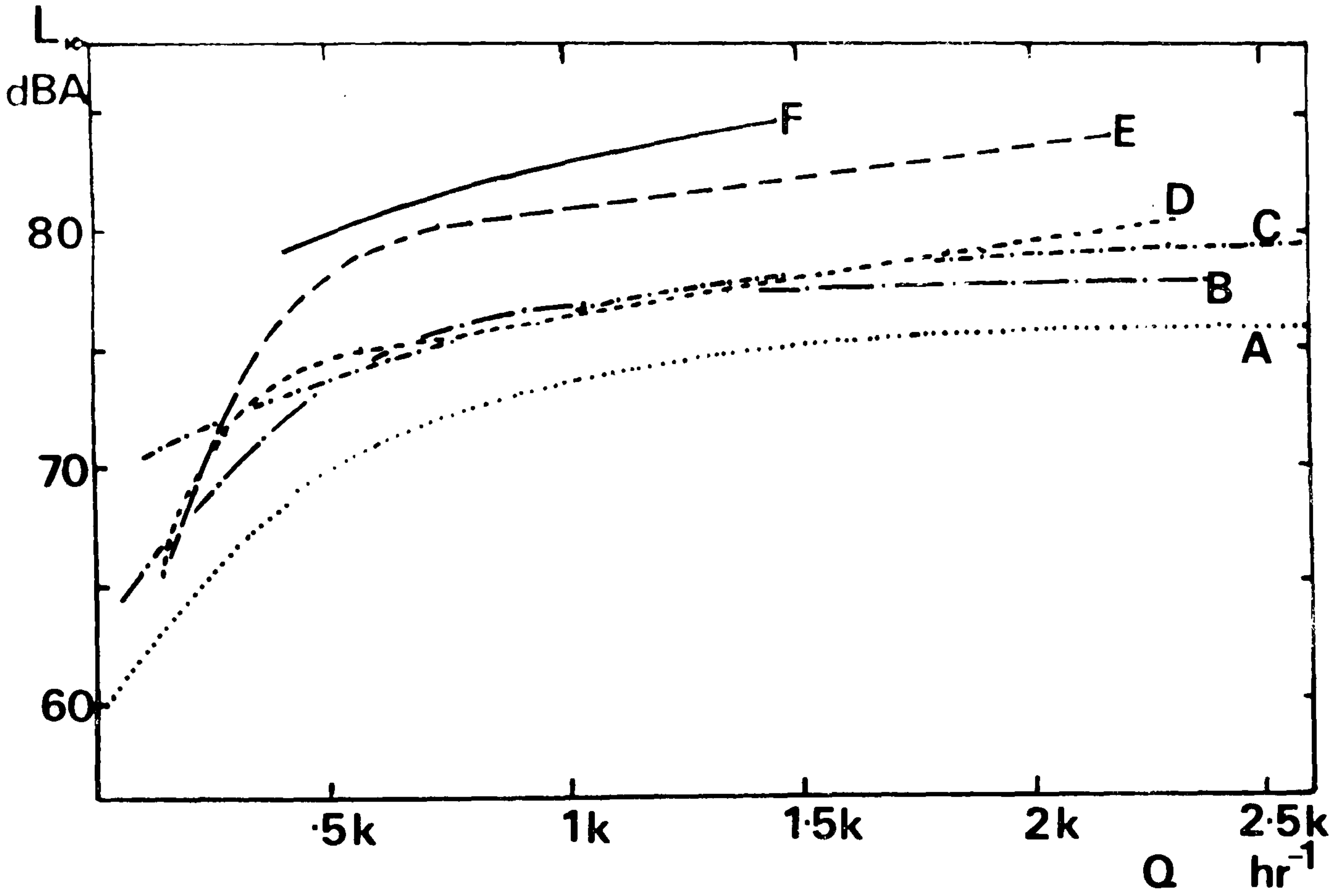


Fig. 5.2 Variation of L_{10}, at kerbside, with rate of flow Q for different percentages of heavy vehicles, as indicated below (after Vulkan (34)).

A Under 16 per cent.

B 16 to 20 per cent.

C 20 to 25 per cent.

D 25 to 33 per cent.

E 33 to 50 per cent.

F Over 50 per cent.

Mention should be made of measurements carried out at kerbside in more congested areas by Crompton (35) who chose some 190 sites in Edinburgh and Canterbury where the traffic speed was of the order of 20 m.p.h. (32 km hr^{-1}). Regression equations were obtained for L_{10}, L_{50} and L_{90}, considering vehicle density Q and percentage p of heavy lorries. For L_{10} they also took into account a parameter T, the value of which depends on the "pattern of arrival of traffic". For both L_{50} and L_{90} the mean speed v of traffic was considered important because of its effect on increasing the spacing between the vehicles and thus reducing noise levels. It was found that at a speed of the order of 32 km hr^{-1} variations of vehicle speed had little effect on noise level. L_{10}, however, was shown to be independent of speed. Crompton also observed that L_{50} was affected by the road width, W, because of the dependency on it of the rate of flow. The equations were as follows:

$$L_{10} = 44.37 + 10.23 \log_{10} Q (1 + 0.09 p) + 1.61 T \qquad 5.1$$

$$L_{50} = 40.35 + 14.10 \log_{10} Q (1 + 0.04 p) - 4.71 \log_{10} vW \qquad 5.2$$

$$L_{90} = 30.05 + 12.99 \log_{10} Q (1 + 0.04 p) - 9.20 \log_{10} V \qquad 5.3$$

Variations of L_{10} and L_{50} do not appear to agree with those of Stephenson and Vulkan. We see, for example, that no departure from linearity is allowed for at low densities. The effect of heavy vehicles appears to be less than those observed by Stephenson and Vulkan, there being increases in L_{10} and L_{50} of about only 1.5 or so dBA on doubling the percentage of heavy vehicles. Higher increases, however, were observed for doubling of traffic density, these being 4.2 dBA and 3 dBA for L_{50} and L_{10}, respectively.

5.3 MEASUREMENTS IN TRUNK ROADS AND MOTORWAYS

Although the main purpose of the present work is to investigate road traffic noise in urban areas it is of interest to consider noise from traffic travelling at high speeds on motorways and other trunk roads in this country. A number of investigations into this aspect have been made, the most ambitious one being conducted by Johnson and Saunders (36) of the National Physical Laboratory. Recently Delany (37) made a detailed study of their results and by applying multiple regression analysis produced the following empirical relationships and obtained values of L_{10}, L_{50} and L_{90}, as follows.

$$L_{10} = 17.56 + 16.36 \log_{10} v + 8.79 \log_{10} Q + 0.118p \text{ dBA} \quad \text{with } r = 0.92 \qquad 5.4$$

$$L_{50} = -2.00 + 11.72 \log_{10} v + 15.01 \log_{10} Q + 0.0941\, p \text{ dBA} \quad \text{with } r = 0.91 \qquad 5.5$$

$$L_{90} = -24.34 + 9.97 \log_{10} v + 21.30 \log_{10} Q + 0.0755p \text{dBA} \quad \text{with } r = 0.89 \qquad 5.6$$

Here v = mean speed of traffic

Q = number of vehicles per hour

p = percentage of heavy vehicles

r = correlation coefficient

In each case the point of observation is situated at a reference distance of 7.5 m from the traffic stream. Attenuations for increase in distance d from the stream are as follows:-

For L_{10} 10.5 $\log_{10}d$ for a concrete surface and 14.8 $\log_{10}d$ for grassland.

For L_{50} 8.4 $\log_{10}d$ for a concrete surface and 11.1 $\log_{10}d$ for grassland.

For L_{90} 6.1 $\log_{10}d$ for a concrete surface and 8.2 $\log_{10}d$ for grassland.

The validity of the equations 5.4, 5.5 and 5.6 depends on the following conditions

$$50 \leq V \leq 101 \text{ km hr}^{-1}$$

$$780 \leq Q \leq 4500 \text{ hr}^{-1}$$

$$4 \leq p \leq 52 \text{ per cent}$$

A discussion of these findings with reference to theoretical predictions is given in section 6.4.

5.4 THE EFFECTS OF GRADIENT ON ROAD TRAFFIC NOISE.

Very little has, at present, been done on the investigation of traffic noise in hilly roads and the main purpose here is to determine how this noise varies with gradient. Galloway and Clark (38) made sample checks on individual cars and heavy vehicles climbing a 5 per cent gradient and ooncluded that the noise level for cars was the same as for level roads. For heavy vehicles they predicted that for level roads, at a distance of 100 ft from the roadside

$$L = 44 + 30 \log_{10}v \qquad 5.7$$

with a standard deviation of 2.8 dB

and for roads having a gradient of 5 per cent

$$L = 66 + 20 \log_{10}v \qquad 5.8$$

with a standard deviation of 2.0 dB

where v is the speed in m.p.h. and L the noise level in PNdB.

For a speed of 25 m.p.h. (40 km hr^{-1}) it is seen that the effect of the gradient is to increase the noise level by anything between 3 and 13 PNdB.

In later work, however, Galloway, Clark and Kerrick (24) found that the noise level of a heavy lorry was increased by only 2 dBA when climbing a gradient of 5 per cent. A recent paper by Gordon, Galloway, Kugler and Nelson (45) concerning trunk roads in the U.S.A. reported variations of noise levels of heavy vehicles with gradient (see Table 5.1). The effect of gradients on light vehicles was negligible. The values given in the table were used in predicting both L_{10} and L_{50} for freely flowing traffic (see Chapter 6).

Johnson and Saunders (30) in their investigations of L_{50} included measurements at two sites on trunk roads, one having a gradient of 1 in 11 (9.1 per cent) and the other of 1 in 8 (12.5 per cent). For a speed of 40 m.p.h. (64 km hr^{-1}) and for 20 per cent heavy vehicles an increase of 6 dBA was observed for L_{50} as compared with the value for level roads in the first case and 8 dBA in the second. The effect of the gradient was found to increase with higher densities of heavy vehicles.

Stephenson and Vulkan (22) conducted a few measurements at L_{10} and L_{50} on hills and observed a considerably greater rise in noise levels for heavy vehicles than for light vehicles on climbing but insufficient data was recorded to obtain conclusive results. They stated, however, that Highgate Hill with a gradient of 1 in 12 (8.3 per cent) carrying a large number of heavy lorries, is one of the noisiest roads in London.

TABLE 5.1

VARIATION OF NOISE LEVELS OF INDIVIDUAL TRUCKS FLOWING FREELY ON TRUNK ROADS (AFTER GORDON ET AL (45)).

GRADIENT	CHANGE IN NOISE LEVEL
$\leq$ 2%	Negligible
3 - 4%	+ 2 dBA
5 - 6%	+ 3 dBA
$\geq$ 7%	+ 5 dBA

Scholes and Sargent (20) expressed the view that the reduction in noise due to the decrease in speed of freely flowing traffic climbing hills tends to reduce any increase in noise which may arise from the effects of the gradients of up to 8 per cent. They predicted for L_{10} an increase of 1 dBA for gradients of from 2 to 4 per cent and 2 dBA for gradients of from 4 to 8 per cent. It was recognised that for built-up areas subjected to 30 m.p.h. (48 km hr^{-1}) speed limits and on slopes steeper than 8 per cent the effects of the gradient may be more pronounced.

In previous work the author ~~working~~ with Grover (39) obtained values of L_{50} at the kerbs at 12 sites on urban roads having various gradients ranging from 1.2 to 8.3 per cent. The results normalised to 1200 vehicles per hour with 16 per cent heavy vehicles, in accordance with Stephenson and Vulkan's results for level roads (Fig. 5.1) are shown in Fig. 5.3. The variation of L_{50} with gradient was found to increase initially by 7 dBA to a peak at about 4.5 per cent and then slightly decrease with increasing gradient. The peak was thought to result, from gear changing in heavy lorries. However insufficient data was obtained in the short time available to obtain more conclusive results. In the present investigation the effects of gradients on L_{10}, L_{50} and L_{90} are observed for a much larger number of sites for wide ranges of traffic densities and percentages of heavy traffic and the results are given in Chapters 9 and 10.

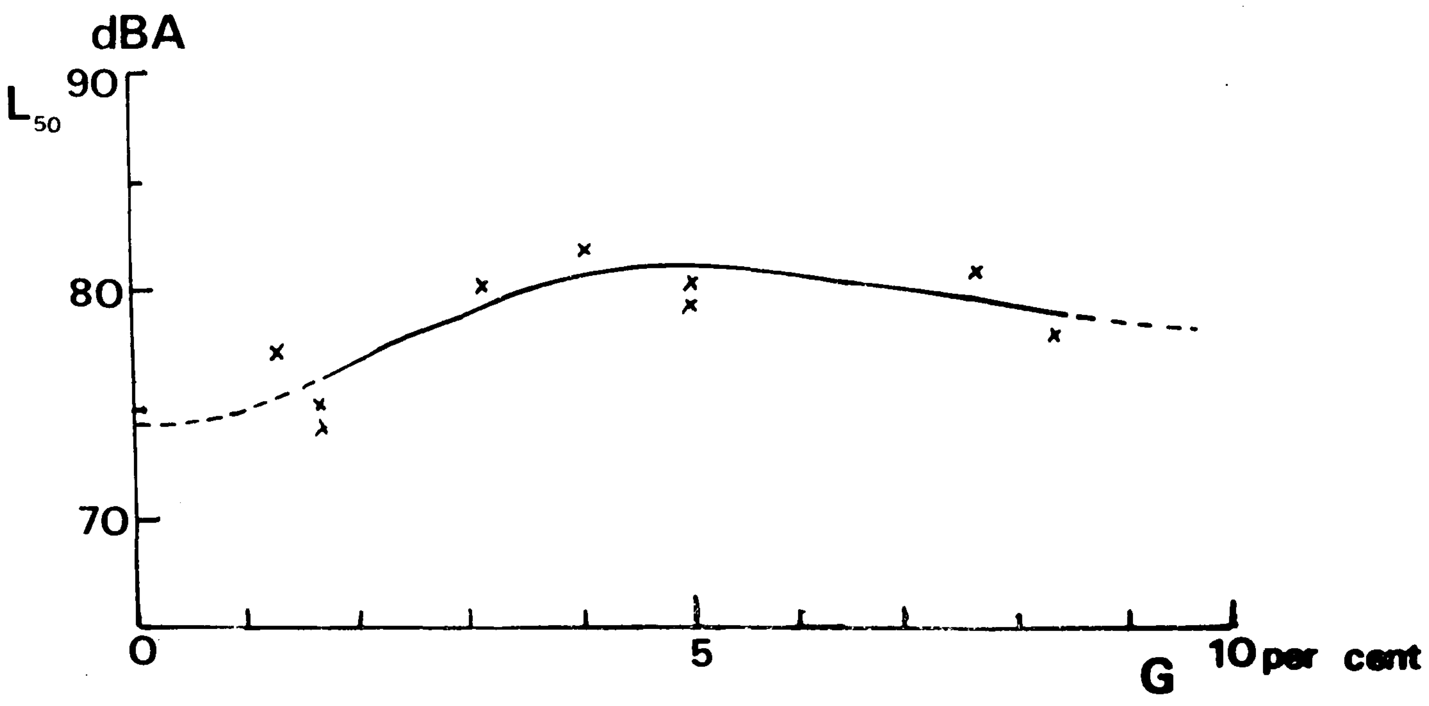


Fig. 5.3 Variation of L_{50} at kerbside with gradient G, normalised to a rate of flow of 1200 hr^{-1} and less than 16 per cent heavy vehicles (after Grover and Blitz (39)).

CHAPTER 6.

EXISTING THEORETICAL PREDICTIONS OF ROAD TRAFFIC NOISE.

6.1 INTRODUCTION

A number of methods have been used to predict the behaviour of road traffic noise, using mathematical models. Difficulties arise from the presence of numerous variable quantities, some of which do not respond well to theoretical treatment and resort must then be made to experimental data to obtain a prediction. However, if the number of variables is reduced to a minimum by considering simpler examples of traffic flow, it is possible to make a reasonably accurate forecast of road traffic noise purely from theoretical considerations.

The idea situation for a theoretical prediction is one where traffic flows freely at a constant speed along a level straight single-carriageway road, free from obstructions and hazards, and where the observer is not in the vicinity of reflecting surfaces, e.g. buildings and walls. The number of types of vehicles, classified according to their noise outputs should be as small as possible; in practice two classes, i.e. heavy and light vehicles, can be specified and variabilities taken into account by means of standard deviations, e.g. 80 dBA and 70 dBA at a given distance for single moving heavy and light vehicles respectively, with a standard deviation of 2.5 dBA in each case. Under these circumstances it is possible to forecast noise levels for given values of traffic densities, vehicle speeds, and distance of the observer from the line of flow of traffic, taking into consideration all classes of vehicles.

When predicting theoretical traffic noise levels, the acoustic radiation from an array of point sources along a line is usually considered. For one type of method, the effect of a series of random "snapshots" of short duration, e.g. 0.1s, of the array of sources and different times is computed. For another, the continuous motion of the sources is taken into account. It may appear advantageous to consider a statistical distribution in the spacing of the vehicles, but, for simplicity, uniform spacing is often assumed. It will be seen that this latter assumption does not lead to any serious discrepancies in predicting noise levels.

6.2 NON-STATISTICAL PREDICTIONS OF ROAD TRAFFIC NOISE

A simple method of predicting road traffic noise levels was put forward by Rathé (33) and applied by Johnson and Saunders (36). It assumed a flow of vehicles, equally spaced apart by distance s, along a straight line at a constant speed v (Fig.6.1). Each vehicle is considered to have the same acoustic power output. Assuming that a given vehicle passes the point nearest to the observer (i.e. at a distance d) at a time t = 0, the resultant intensity I at any time t is given by

$$I = P\sum_{n=-\infty}^{n=+\infty}\frac{1}{d^2 + (vt+ns)^2} \qquad 6.1$$

Here n is an integer (i.e. $0, \pm 1, \pm 2$, etc.) and P a parameter having the dimensions of power and a value dependent on the strength of the source and the characteristics of the wave propagation. The summation of equation 6.1 is given by (40):

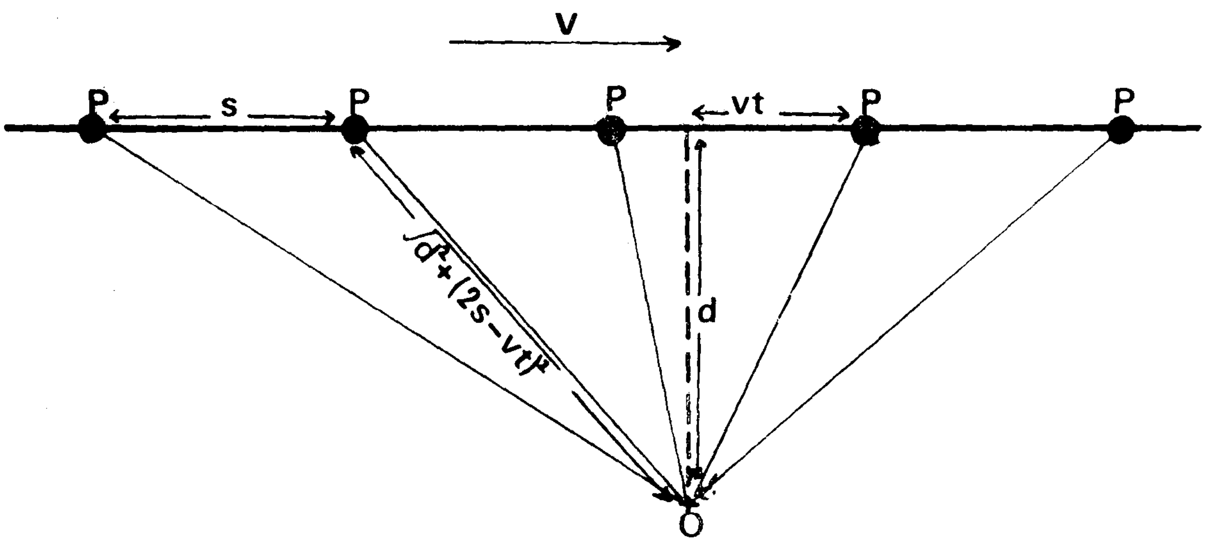


Fig. 6.1 Array of point sources P relative to the observer O, used in Rathé's theoretical prediction.

$$I = P\frac{\pi}{sd}\left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - \cos(2\pi vt/s)}\right] \qquad 6.2$$

In the above expressions the inverse square law of propagation from a point source into a semi-infinite medium is assumed. This is justified from experimental observations, provided that the effects of reflections and of attenuation in the air are neglected.

The ~~loudness~~ level L in dBA corresponding to I is given by

$$L = 10\log_{10}\frac{\pi}{sd}\left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - \cos(2\pi vt/s)}\right] + L_{ref} + 20\log_{10} d_0 \qquad 6.3$$

where L_{ref} is a reference level in dBA corresponding to a reference intensity $I_{ref} = P/d_0^2$ where d_0 is a reference distance, often taken as 7.5 m. Thus

$$L_{ref} = 10\log_{10} P - 20\log_{10} d_0 \qquad 6.4$$

Equation 6.3 may be more conveniently written as

$$L = L' + L_{ref} + 20\log_{10} d_0 \qquad 6.3\,(a)$$

where $$L' = 10\log_{10}\frac{\pi}{sd}\left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - \cos(2\pi vt/s)}\right] \qquad 6.5$$

Fig.6.2 shows the variation of L' with time in accordance with the above equation.

L' is a maximum when a noise source is at a distance d from the observer, for which t = ns/v, where n = 0, ± 1, ± 2, etc. The corresponding value L' = L'_{max} is then given by

$$L'_{max} = 10 \log_{10} \frac{\pi}{sd} \left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - 1} \right] \qquad 6{\cdot}6\,(a)$$

$$\text{i.e.} \qquad L'_{max} = 10 \log_{10} \frac{\pi}{sd} \coth \frac{\pi d}{s} \qquad 6{\cdot}6\,(b)$$

L' is a minimum, i.e. L'_{min}, when the midpoint between two consecutive vehicles is opposite the observer, for which t = (2n + 1)s/2v where n = 0, ± 1, ± 2, etc. Thus:

$$L'_{min} = 10 \log_{10} \frac{\pi}{sd} \left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) + 1} \right] \qquad 6{\cdot}7\,(a)$$

$$\text{i.e} \qquad L'_{min} = 10 \log_{10} \frac{\pi}{sd} \tanh \frac{\pi d}{s} \qquad 6{\cdot}7\,(b)$$

The mean ~~loudness~~ level is given by L'_{50}, i.e. the level exceeded for 50 per cent of the time, and occurs for quarter-period positions when t = (2n + 1)s/4v, where n = 0, ± 1, ± 2, etc. corresponding to cos $(2\pi vt/s) = 0$, i.e.

$$L'_{50} = 10 \log_{10} \frac{\pi}{sd} \tanh \frac{2\pi d}{s} \qquad 6{\cdot}8$$

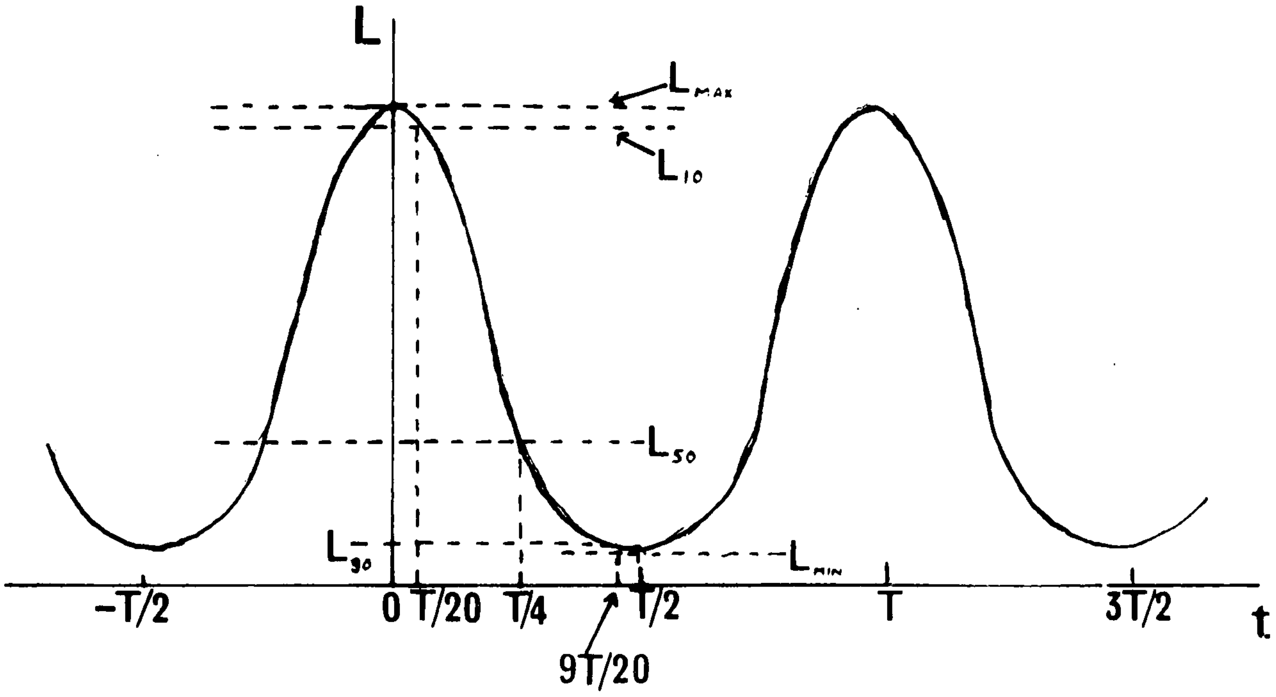


Fig. 6.2 Variation of sound level L with time t in accordance with equation 6.3, indicating L_{max}, L_{10}, L_{50}, L_{90} and L_{min}.

Fig. 6.3 shows how L'_{50} varies with s and hence rate of flow Q of traffic for a given speed and for different values of d.

The absolute loudness levels in dBA, corresponding to L'_{max}, L'_{min} and L'_{50}, are L_{max}, L_{min} and L_{50} respectively obtained by the addition of $L_{ref} + 20 \log_{10} d_o$.

For high and low rates of traffic flow, the equations 6.6, 6.7 and 6.8 can be simplified because of the corresponding behaviour of the hyperbolic functions of d/s. Thus when $d \gg s$, i.e. for high rates of flow, $\tanh(2\pi d/s)$, $\tanh(\pi d/s)$ and $\coth(\pi d/s)$ tend to unity. Also when $d \ll s$, i.e. for low rates of flow, $\tanh(2\pi d/s) \rightarrow 2\pi d/s$, $\tanh(\pi d/s) \rightarrow \pi d/s$, and $\coth(\pi d/s) \rightarrow s/\pi d$

Assuming a tolerance of 0.5 dBA in the measurement of L, the following approximations are then valid:

$$L'_{max} = 10 \log_{10} \frac{\pi}{sd} \quad \text{for} \quad \frac{d}{s} \geqslant \frac{1}{2} \qquad 6.9\,(a)$$

$$L'_{max} = 10 \log_{10} \frac{1}{d^2} \quad \text{for} \quad \frac{d}{s} \leqslant \frac{1}{6} \qquad 6.9\,(b)$$

$$L'_{min} = 10 \log_{10} \frac{\pi}{sd} \quad \text{for} \quad \frac{d}{s} \geqslant \frac{1}{2} \qquad 6.10\,(a)$$

$$L'_{min} = 10 \log_{10} \frac{\pi^2}{s^2} \quad \text{for} \quad \frac{d}{s} \leqslant \frac{1}{6} \qquad 6.10\,(b)$$

$$L'_{50} = 10 \log_{10} \frac{\pi}{sd} \quad \text{for} \quad \frac{d}{s} \geqslant \frac{1}{4} \qquad 6.11\,(a)$$

$$L'_{50} = 10 \log_{10} \frac{2\pi^2}{s^2} \quad \text{for} \quad \frac{d}{s} \leqslant \frac{1}{12} \qquad 6.11\,(b)$$

It is often more convenient to express the noise levels in terms of traffic density rather than the vehicle spacing s.

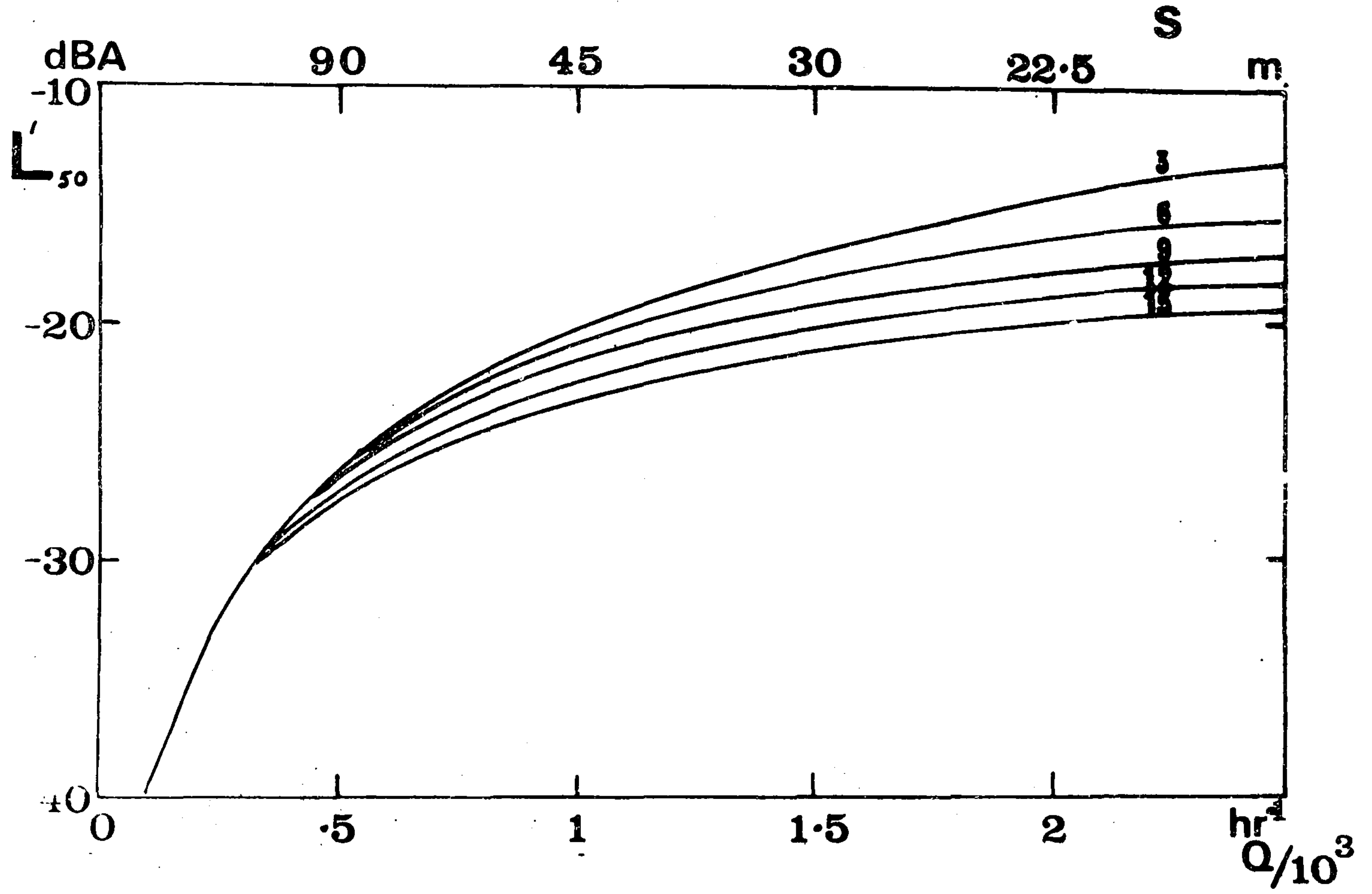


Fig. 6.3 Variation of L'_{50} with s and Q ($v = 45\ m\ s^{-1}$) in accordance with equation 6.8 for different values of d in metres, as indicated by the numerals.

Thus if N is the number of vehicles per km when s is expressed in metres we have:

$$N = 1000/s \tag{6.12}$$

On the other hand if we have a constant speed V expressed in km hr^{-1} such that $V = 3.6\ v$, where v is the speed in m s^{-1}, the traffic density can be expressed in the number Q of vehicles flowing per hour, i.e.

$$Q = 3600\ v/s = 1000\ V/s \tag{6.13}$$

We also see that

$$Q = NV \tag{6.14}$$

When the traffic is dense or when the observer is stationed at a ~~large~~ distance from the road large compared with the vehicle spacing, we see from equations 6.9(a), 6.10(a) and 6.11(a) that the values of L_{max}, L_{min} and L_{50} become equal. The array of traffic then approximates to a line source and the intensity varies inversely with distance, i.e. L decreases by 3 dB for doubling of distance, for a given rate of flow. Alternatively, for a fixed position of the observer the intensity varies inversely with s and thus directly with Q, for a given velocity, i.e. L increases by 3 dB when the rate of flow is doubled.

When the traffic density is low or when the observer is located close to the line of traffic flow, the observed maximum intensity is a function only of the amount of energy radiated from the individual source opposite the observer and is independent of the vehicle spacing s and thus the rate of flow Q.

The maximum intensity then varies with distance in accordance with the inverse square law, i.e. L_{max} decreases by 6 dB when the distance between the observer and the line of traffic is doubled (see equation 6.9(b)). At the same time we see from equations 6.10(b) and 6.11(b) that both L_{min} and L_{50} are independent of d and that their values are determined only by the amount of spacing, i.e. the rate of flow. L_{min} and L_{50} both increase by 6 dBA when the traffic density is doubled.

It is unfortunate that the approximations given in equations 6.9, 6.10 and 6.11 are of limited use when dealing with traffic flow in urban main roads, i.e. they are valid only for very heavy traffic densities, typical of motorways, or for very light densities. In the investigation forming the major part of this thesis we are concerned mainly with rates of flow ranging from 500 to 1500 hr^{-1} for which the approximations do not hold. However, if we are concerned only with heavy vehicles, the approximation can be used to ones advantage when the rate of flow is less than 500 hr^{-1}.

Johnson and Saunders (36) did consider reference levels from individual vehicles in their prediction of L_{50} but applied actual values of L_{50} taken from numerous measurements at different distances from the roadside on a number of main roads, including motorways. These roads were open on both sides and clear of obstructions, carrying freely flowing fast traffic. Their results were normalised to correspond to a mean speed of 40 m.p.h. and to 20 per cent heavy vehicles. To do this they used empirical relationships, based on their observations, i.e. that L_{50} varies linearly with $30 \log_{10} V/40$, where V is the mean speed in m.p.h., and increases by 1 dB for each increase of 20 per cent heavy vehicles. Sets of curves relating L_{50} with traffic density Q, similar to those shown in Fig.6.3, for different distances from the traffic stream were then obtained, in accordance with equation 6.8.

Johnson and Saunders took into account the combined effect of traffic from nearside and farside lanes for a given distance of the observer from the roadside. The mean distances d_1 and d_2 from the flows of traffic in these respective lanes were first determined. Values of Q for both lanes were then initially normalised for a speed of 40 m.p.h. by multiplying by the factor 40/V, where V is the mean speed in each lane; this kept s consistent with the speed of 40 m.p.h. The value of L_{50} corresponding to the normalised Q for the farside lane was determined from the graph of L_{50} against Q (e.g. Fig. 6.3) for the distance d_2 for that lane and corrected for speed and for percentage of heavy vehicles. Corrections for speed and for heavy vehicles in the nearside lane were then subtracted from this value to provide an effective L_{50} for that lane, contributed by the farside lane. The corresponding value of Q, relating to the distance d_1 of the nearside lane, was then read off the graph. This was added to the normalised value of Q for the nearside lane to provide a total effective rate of flow at a distance d_1. The corresponding value of L_{50} was then read from the graph. After allowing for speed and heavy vehicles, this was the predicted value of L_{50} for the site. Corrections were made where necessary for reflections at the road surface and hard shoulder, estimated as an increase of 1 dBA, and for any excess alteration due to absorption by grassland, estimated as 1 dB per 100ft. The writer does not feel that corrections for reflections are necessary in view of the fact that they must already have been accounted for in determining the reference levels.

From the noise level distributions used to determine measured values of L_{50}, Johnson and Saunders derived the standard deviations σ and obtained a graphical relationship between σ and Qd, with Q normalised to 40 m.p.h. In this way values of L_{10} and L_{90} can be predicted, but no details of this were given in their paper. However, values of L_{10} were computed from Johnson and Saunder's data on L_{50} and σ by Scholes and Sargent (20) who plotted families of curves relating L_{10} with Q for different values of d, assuming a single line of flow. L_{10} is related to L_{50} and σ as follows:

$$L_{10} = L_{50} + 1.3\sigma \qquad 6.15$$

At 100 ft. (30 m) from the line of flow they predicted, for example, that L_{10} increases by about 2.2 dBA for doubling the rate of flow whilst the speed remains constant at 40 m.p.h. (64 km hr^{-1}), for Q ranging from 300 to 20,000 hr^{-1}. Their curves predict an approximate decrease of 4 dBA for doubling the distance between the observer and the line of traffic for a constant Q and speed.

Scholes and Sargent also corrected for traffic speed, predicting an increase in L_{10} of nearly 10 dBA for doubling of mean velocity as opposed to a corresponding increase in L_{50} of only 9 dBA. This is because the effect of doubling the mean vehicle spacing s caused by doubling the velocity, for a given value of Q, is to reduce L_{10} by only 2.2. dBA as compared with a reduction in L_{50} by 3 dBA.

Gordon, Galloway, Kugler and Nelson (45) applied Rathé's method to predict L_{10} as well as L_{50}. The value of L_{10} is determined from equation 6.3 by putting $\cos(2\pi vt/s)=0.95$ (see equation 7.1). Combining this with equation 6.8 gives

$$L_{10} - L_{50} = 10\log_{10}\left[\frac{\cosh(2\pi d/s)}{\cosh(2\pi d/s) - 0.95}\right] \qquad 6.16$$

where $L_{10} - L_{50}$ is the correction factor to be added to L_{50} to yield L_{10}. In their detailed evaluations they used a method similar to that of Johnson and Saunders (36), derived earlier, in which values of Q were normalised for a given distance, account being taken of the number of lanes, speed, and gradient as well as effects of elevations, curves, and barriers.

The effects of heavy ~~traffic~~ vehicles were taken into account in the prediction of both L_{50} and L_{10} simply by adding together the corresponding intensities for both heavy and light vehicles and converting the result to provide a corrected value of L_{50} or L_{10}. The validity of this method is questionable; its use may be justified to predict L_{50}, and possibly L_{10} for high values of d/s, but it is most certainly not applicable for the range of values of flow of traffic in which we are interested. This can easily be seen by selecting corresponding values of L_{50} and Q and L_{10} and Q from Figs 6.3 and 7.1. For example, consider two classes of vehicles having the same reference level and for which the rates of flow Q are each 500 hr^{-1}. Taking $d = 15$ m and $v = 45$ km hr^{-1} we find from Fig.7.1 that, for $Q = 500$ hr^{-1}, $L'_{10} = 23.49$ dBA. Adding up two equal values of L'_{10} to correspond to a total of $Q = 1000$ hr^{-1} gives -20.49 dBA. However, Fig.7.1 shows that $L'_{10} = -22.31$ dBA when $Q = 1000$ hr^{-1}, i.e. there is a discrepancy of ~~more than~~ nearly 2 dBA.

6.3 STATISTICAL PREDICTIONS OF ROAD TRAFFIC NOISE

Rathé's prediction of road traffic noise levels assumed that the vehicles in a line of traffic were spaced equally apart. This, of course, is not the case in practice; the spacing between vehicles is random in nature and a number of suggestions have been made as to the type of distribution of the spacings, as will be seen later in this section. One technique used is not to consider a continuous variation of intensity with time but to study the various possibilities of random vehicle separations and to deduce noise levels from statistical considerations.

Weiss(41) proceeding directly from the method used by Rathé and by Johnson and Saunders assumed that the probability of vehicle spacing s is given by an exponential function, i.e. $1/s \exp(-x/s)$ where x is measured along the line of traffic. He deduced that the mean value $\bar{I}$ of intensity, corresponding to L_{50} is given by

$$\bar{I} = \frac{P\Pi}{sd} \qquad 6.17$$

where P is the effective acoustic power, as defined in equation 3.4, of each of the sources, assumed to be identical. This is equivalent to

$$L'_{50} = 10 \log_{10} \frac{\Pi}{sd} \qquad 6.18$$

where L'_{50} is defined in terms of L_{50} in accordance with equation 6.3(a).

Equation 6.18 is the same as equation 6.11(a), which applies when $d/s \geqslant \frac{1}{4}$, i.e. low traffic densities. Weiss also deduced a value of standard deviation σ' applying to <u>intensities</u> as given by

$$\sigma' = P\left(\frac{\pi}{2d^3 s}\right)^{\frac{1}{2}} \qquad 6.19(a)$$

from which a Gaussian distribution curve for L can be obtained and hence the value of L_{10}.

By analogy, Weiss deduced the value of σ' using Johnson and Saunder's (i.e. Rathé's) model, i.e.

$$(\sigma')^2 = \frac{2(P\pi/ds)^2}{\exp[(4\pi d/s) - 1]} \qquad 6.19(b)$$

One sees that equations 6.19(a) and 6.19(b) are identical when $d/s \rightarrow 0$, i.e. for ~~high~~ low traffic densities but, for high values of d/s, the differences between the two values of σ' can be large.

Weiss's attempts to predict road traffic noise levels using a statistical approach is of limited use because he considered that the sources, i.e. the vehicles, all had equal acoustic intensities. Kurze (42) (45) has produced a more ambitious model, assuming that the array of traffic on a road follows a Poisson distribution and was able to predict values of noise levels for various percentages of time (e.g. L_{10}, L_{50}, etc.) with mixtures of both light and heavy vehicles.

Kurze (42) introduced the parameter $\lambda = 1/s$ (where s is the average spacing between vehicles as before, and assumed that vehicles proceed at constant speed along a straight road serving as the y axis of a Cartesian co-ordinate system, the x-axis of which is the perpendicular from the observer to the line of traffic (see Fig.6.4). The average number of vehicles, assumed to be point sources between two positions $(0,y_1)$ and $(0,y_2)$ is equal to $\lambda(y_2-y_1)$.

If r is the distance between the observer and the nearest point on the part of the road under consideration (i.e. between $(0,y_1)$ and $(0, y_2)$), the average number of point sources over a length r of the road is given by

$$M = \lambda r = \lambda d/\cos\alpha_{min} \qquad 6.20$$

where α_{min} is the angle between the x-axis and the radius vector r and d the perpendicular distance from the observer to the road. Taking the extreme case, in which we are mainly interested, for which the source line stretches from $y_1 \ll 0$ to $y_2 \gg 0$, we see that

$$M = \lambda d = d/s \qquad 6.20(a)$$

Suppose, first of all, that the point sources having equal intensities are separated by equal gaps $s = 1/\lambda$ over a section of length $y_2 - y_1$. Provided that $N \geq 3$ and $M \geq 1/\pi$, i.e. $d/s \geq 1/\pi$, the sound level can be shown, to the nearest 1 dB, to approximate to

$$L_e = L_{ref} + 10\log_{10}(d_o^2/d)\lambda(\alpha_2 - \alpha_1) \qquad 6.21$$

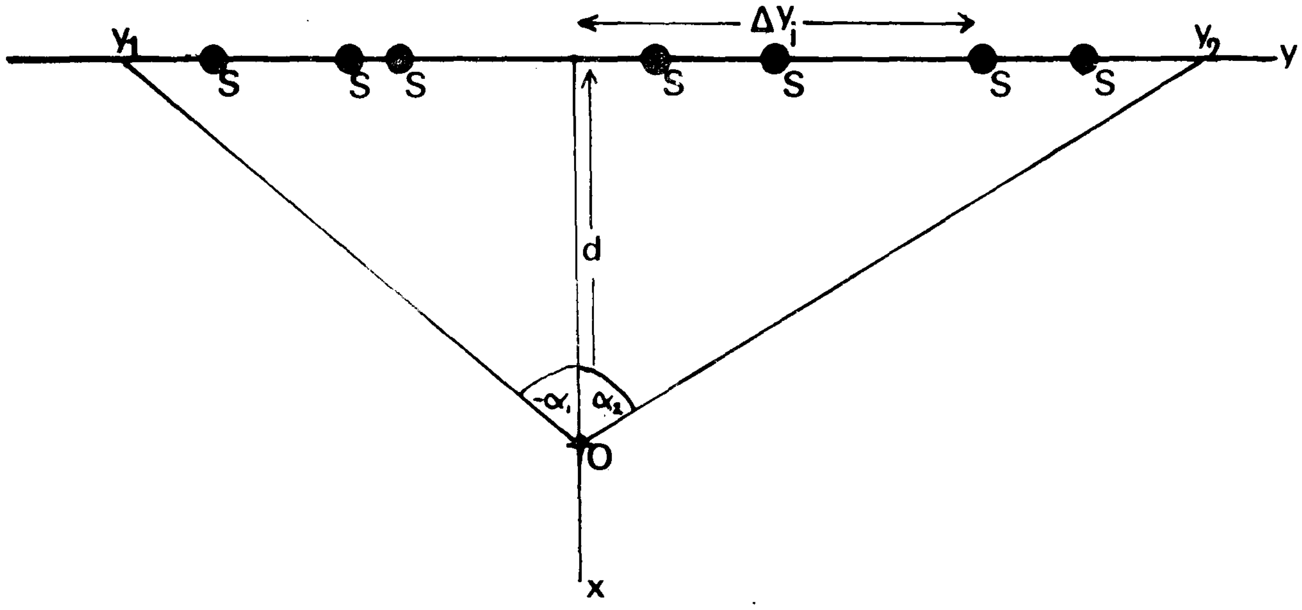


Fig. 6.4 Array of sources S relative to the observer O used in Kurze's theoretical prediction.

where L_{ref} is the reference level in dBA for a distance d_0 from the observer to a single point source, and $\alpha_2 - \alpha_1$ is the angle subtended by the section of length $y_2 - y_1$ of the source line to the observer (see Fig. 6.4). L_e is then the mean level for randomly distributed sources.

We see that for a straight road extending from $y_1 = -\infty$ to $y_2 = +\infty$, for which $\alpha_2 - \alpha_1 = \pi$,

$$L_e = L_{ref} + 20\log_{10} d_0 + 10\log_{10}\frac{\pi}{sd} \qquad 6.21(a)$$

which is in agreement with the values of L given in equations 6.9(a), 6.10(a) and 6.11(a) where $M = d/s \geqslant \frac{1}{2}$.

For randomly distributed vehicles of equal intensities the sound level L in dBA at the observation point is given in accordance with the inverse square law (see Fig. 6.4) by

$$L = L_{ref} + 10\log_{10}\frac{d_0^2}{d^2}\sum_{i=0}^{n}\frac{1}{1 + (\Delta y_i/d)^2} \qquad 6.22$$

where the location Δy_i and the number n of points are randomly variable. The probability distribution is given by

$$p(\Delta y_i) = \frac{1}{y_2 - y_1} \quad \text{for} \quad y_1 \leq \Delta y_i \leq y_2 \qquad 6.23$$

Assuming a Poisson distribution of vehicles, we have

$$p(n) = \frac{N^n e^{-N}}{n!} \qquad 6.24$$

To obtain the statistical distribution of sound levels, they must be converted to intensities and related to the intensity for uniform distribution of sources, i.e.

$$I_r = 10^{(L-L_e)/10} = k\sum_{i=1}^{n} \frac{1}{1 + (\Delta y_i/d)^2} = k\sum_{i=0}^{n} I_i \qquad 6{\cdot}25$$

where $k = 1/\lambda d\,(\alpha_2 - \alpha_1)$. Here I_r is the ratio of intensity for random distribution to that for the uniform distribution, assuming a given value of λ.

For an infinite road Kurze showed that the probability distribution of I_r approximated to a Pearson Type III distribution from which he obtained variations of mean values m of $L-L_e$ and of standard deviations σ for different values of $M = d/s$ (see Fig. 6.5). With sufficiently high values of d/s, i.e. for high traffic densities, L approaches L_e and σ approaches $1.8\,(d/s)^{\frac{1}{2}}$. Also from the probability distribution he obtained variations of L_{max}, L_{10}, and L_{50} with d/s (see Fig. 6.6).

Kurze (43) then considered the effects of complex traffic conditions for which he modified equation 6.21 as follows:

$$L_e = 10\log_{10}\left[\sum_{s=1}^{S} 10^{L_{ref.s}/10}\,\frac{d_o^2}{d_s}\,\lambda_s\left(\alpha_{2s} - \alpha_{1s}\right)\right] \qquad 6.26$$

By introducing different values of $L_{ref.s}$ for which there are corresponding values of λ_s account can be taken of a mixture of vehicles of different acoustic powers, e.g. private cars and heavy commercial vehicles.

The discrimination between S different angular sections $\alpha_{2s} - \alpha_{1s}$ in the above equations permits the consideration of:

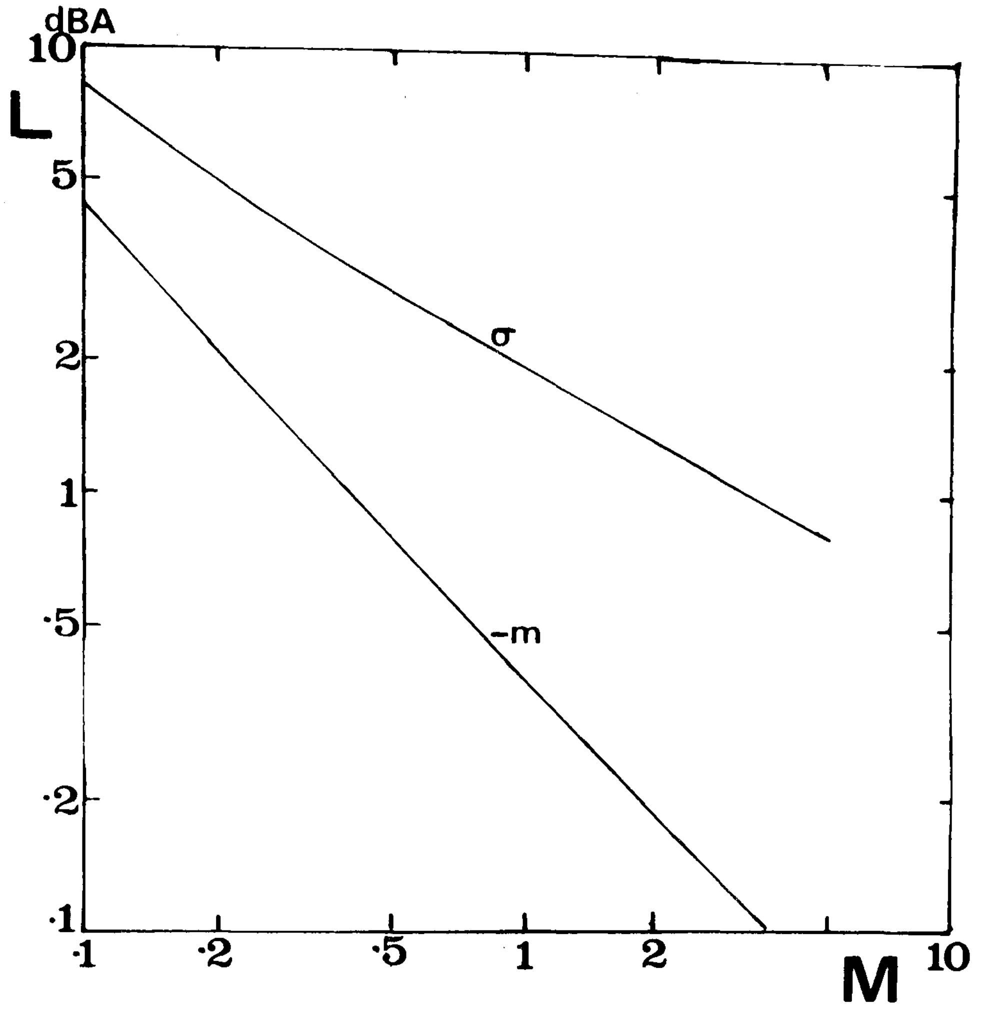


Fig. 6.5 Variations of level L, representing negative mean m of L - L_e and standard deviation with M = d/s (Kurze (42)).

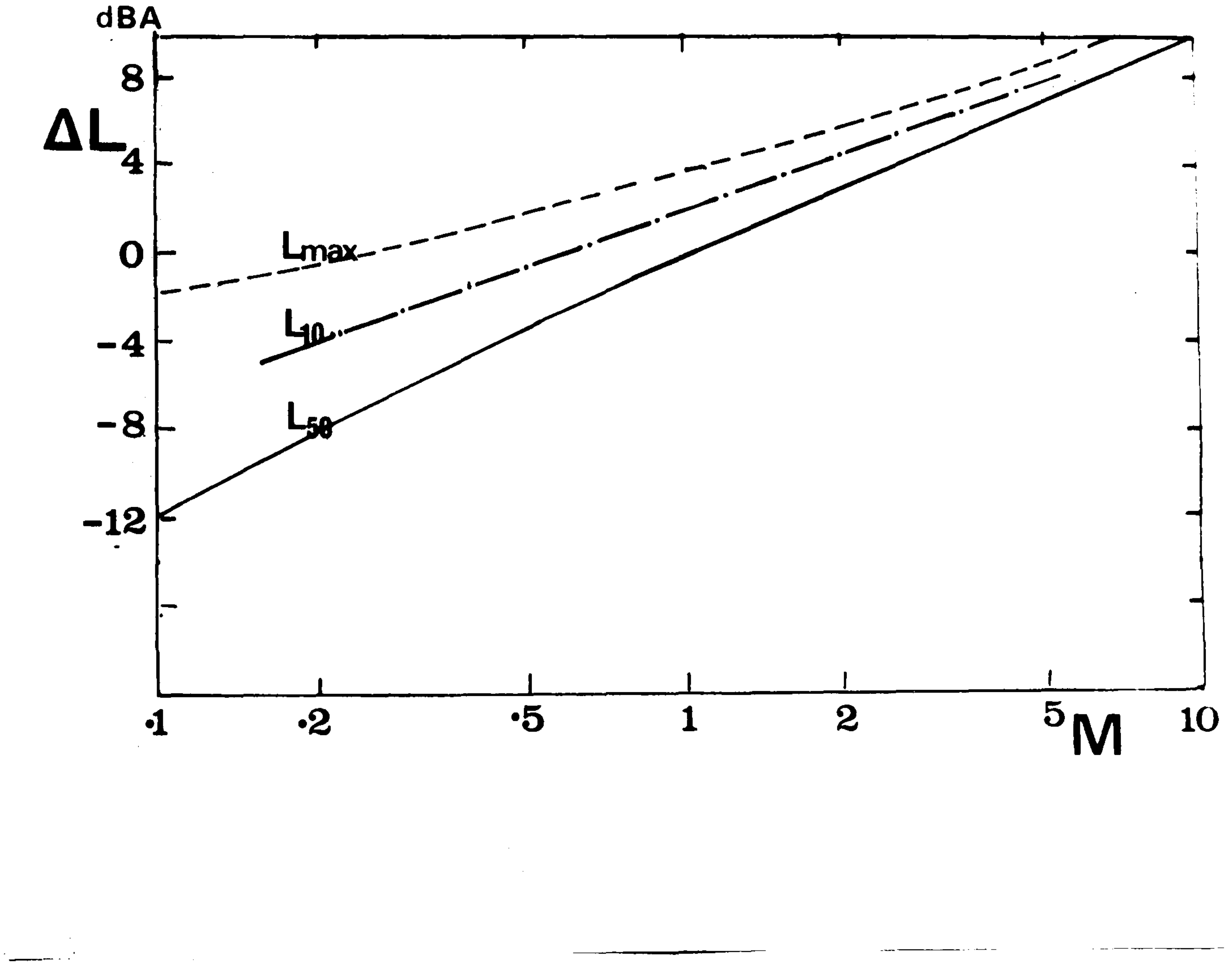


Fig. 6.6 Variations of L, representing L_{max}, L_{10}, and L_{50} with $M = d/s$, as predicted by Kurze (42)).

(i) different reference levels $L_{ref.s}$ for the same type of vehicle which may arise as a result of velocity changes or of the effects of changes in gradient along the stream, etc.

(ii) different concentrations λ_s of the same type of vehicle travelling at different speeds.

(iii) curved roads which can be approximated to a few straight sections each having its characteristic value of d_s.

Different values of d_s in equation 6.26 can take into account the effects of vehicles in different lanes; this is of value in the practical case where lorries are concentrated in the outer lanes and cars in the inner lanes.

Equation 6.25 then becomes:

$$I_{rs} = k_s \sum_{i=1}^{n} \frac{1}{1 + (\Delta y_i / d_s)^2} \qquad 6.27$$

where

$$k_s = \frac{\left(10^{L_{ref.s}/10}\right)/d_s^2}{\sum_{s=1}^{S} \left(10^{L_{ref.s}/10}\right)\lambda_s \left(\alpha_{2s} - \alpha_{1s}\right)/d_s}$$

Using statistical methods Kurze showed how an equivalent vehicle concentration λ_{eq} could be introduced to give a single value of λ_s, i.e.

$$\lambda_{eq} = \frac{\left[\sum_{s=1}^{S} \lambda_s \left(10^{L_{ref.s}/10}\right)\right]^2}{\sum_{s=1}^{S} \lambda_s \left(10^{L_{ref.s}/5}\right) \exp\left(0{\cdot}24\, \sigma^2_{ref.s}\right)} \qquad 6.28$$

where $\sigma_{ref.s}$ is the standard deviation in the level for each type of vehicle, assumed to be about 2dBA for cars and 3dBA for heavy vehicles. He found that λ_{eq} is primarily determined by the noisiest vehicles. For example, with a mixture of 90 per cent cars travelling at 100 km hr^{-1} and 10 per cent heavy lorries at 70 km hr^{-1}, where the individual lorry noise is 15 dBA greater than the individual car noise, assuming a standard deviation $\sigma_{ref} = 2.5$ dBA for each type of vehicle, $\lambda_{cars}/\lambda_{lorries} = 6.3$ and $\lambda_{eq} = 1.04\,\lambda_{lorries}$ i.e. the acoustic intensity is determined virtually only by the heavy vehicles.

Galloway, Clark and Kerrick (24) using a computer to simulate traffic flow considered the frequency content of the sources. The reference sources, after A-weighting, were subjected to octave band analyses, centred at frequencies ranging from 63 to 8000 Hz. To simplify the procedure the number of classes of vehicles was reduced to a minimum by considering the mean spectra for each class. Given an array of vehicles, randomly spaced and moving at a mean velocity $\bar{v}$ along a straight line, the level L in dBA at a point of observation was considered to be

$$L = 10\log_{10}\left[\frac{1}{2\pi I_0}\sum_{i}\sum_{j}\sum_{k} T_k T_k^{*} n_{ij}\bar{I}_{ijk}\frac{d_0^2}{d_i^2}\exp(-2\alpha_k d_i)\right] \qquad 6.29$$

Here $\bar{I}_{ijk}$ is the average intensity in W m^{-2} in the k^{th} octave frequency band of a vehicle of the j^{th} class located at the i^{th}

interval at the mean speed $\bar{v}$, which would be produced at a reference distance d_0 and $I_0 = 10^{-12}$ W m^{-2}. d_i is the distance of the observer from the vehicle at the i^{th} interval, T_k the transfer function of the A-weighted network in the k^{th} band, T_k^* the complex conjugate of T , n_{ij} the number of vehicles in the j^{th} class and α_k the air absorption coefficient in dB m^{-1} in the k^{th} frequency band. It was assumed that the intervals between the vehicles varied with time in accordance with a Poisson distribution.

The traffic flow was simulated by obtaining a large number of "snapshots", each persisting for 0.1s, of different arrays of randomly distributed traffic but having the same rate of Q and mean velocity $\bar{v}$ of flow. ~~In general a different value of L, as determined from equation 6.29.~~ In this way statistical distributions of L , as a function of percentage of traffic, were determined from which mean values of L, i.e. L_{50}, and standard deviations and, hence L_{10}, were obtained.

Fig. 6.7 shows how L_{50} and L_{10} vary with traffic density, expressed in vehicles per mile of roadway, for different values of d at a speed of 50 m.p.h. (80 km hr^{-1}). For densities exceeding 1000 hr^{-1}, L_{50} was predicted to vary to within 2 dBA as follows:

$$L_{50} = 10 \log_{10} 100\, Q/d + 20 \log_{10} \bar{v} \qquad 6.30$$

where d is expressed in feet and the mean speed $\bar{v}$ in m.p.h.

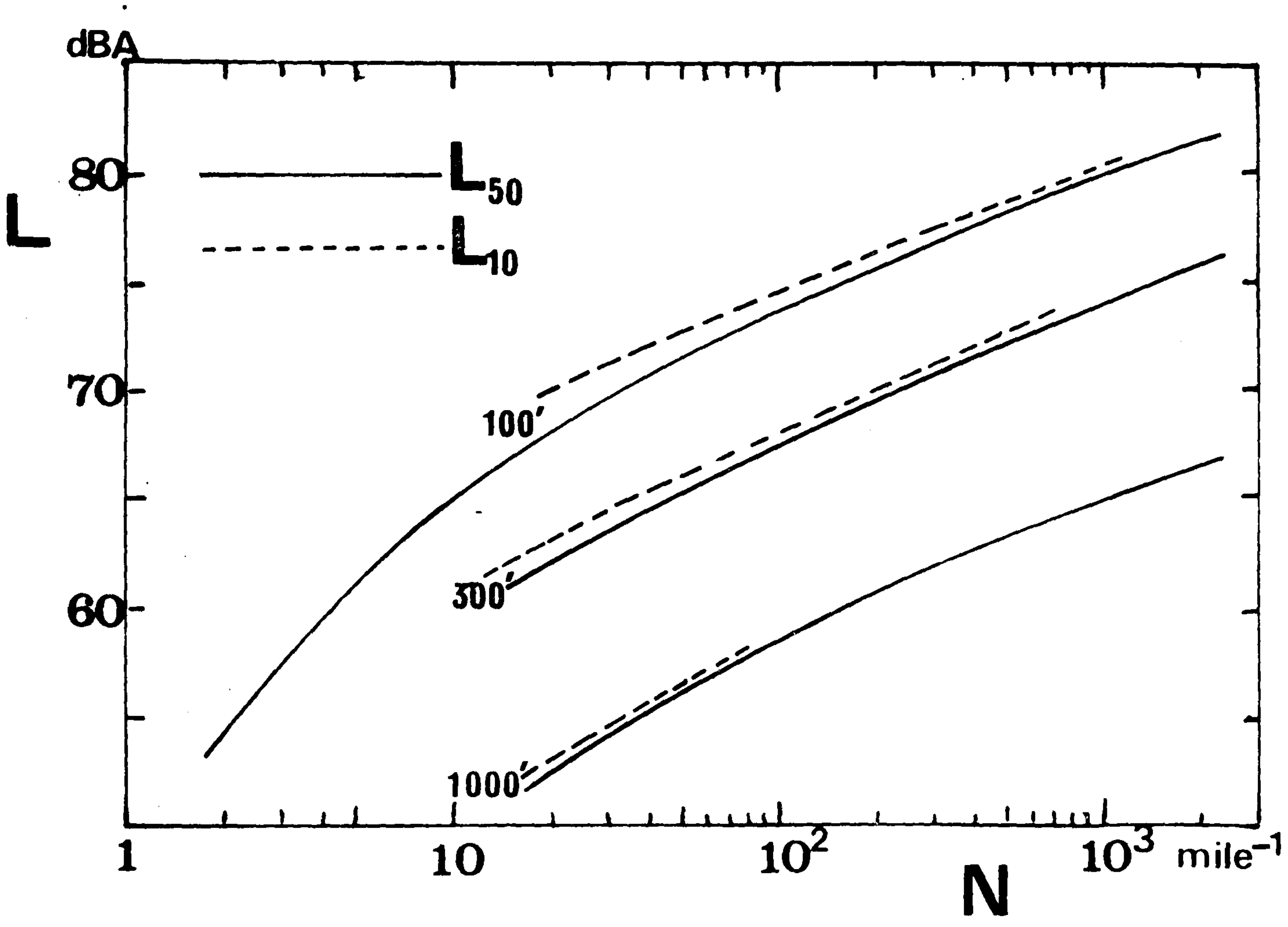


Fig. 6.7 Variations of L_{50} and L_{10} with number N of vehicles per mile for passenger cars flowing along a single lane (or equivalent) at distances of 100, 300, and 1000 ft. from an observer (after Galloway et al (24)).

When d is in m and $\bar{v}$ in km hr^{-1} 4.5 dBA must be subtracted from the value of L_{50} given in the above equation.

The distance d is measured from the effective lane, or pseudo lane. This is displaced from the closest lane to the observer by a distance equal to the square root of the number of lanes times the lane width. Thus for a two lane road the pseudo-lane is located at $\sqrt{2} \times 1 = 1.4$ lane widths from the centre line of the nearest lane.

The effects of heavy lorries is illustrated in Fig. 6.8, indicating the respective variations of L_{50} and L_{10}, for d = 100 ft., with traffic density for different percentages of heavy vehicles. For traffic densities of less than 1000 per hour equation 6.26 was found to be applicable with the following additions to L_{50}, i.e. 1, 2, 4, and 8 dBA for 2.5, 5, 10 and 20 per cent heavy vehicles, respectively.

6.4 COMPARISON OF THEORETICAL PREDICTIONS WITH ONE ANOTHER AND WITH EXPERIMENTAL RESULTS.

To make a fair comparison between the theoretical predictions of L_{10} and L_{50} discussed earlier, one should choose conditions for which they are all claimed to be valid. Thus we shall consider the case for $d \gg s$ for fast freely flowing traffic. Table 6.1 provides a summary of the predicted theoretical changes of L_{10} and L_{50} for (a) doubling the rate of flow Q, (b) halving the distance d of the observer (c) doubling the mean velocity v and (d) increasing the proportion p of heavy vehicles by 10 per cent. In addition, Delany's predictions (37) based entirely on experimental data are shown (see Section 5.2).

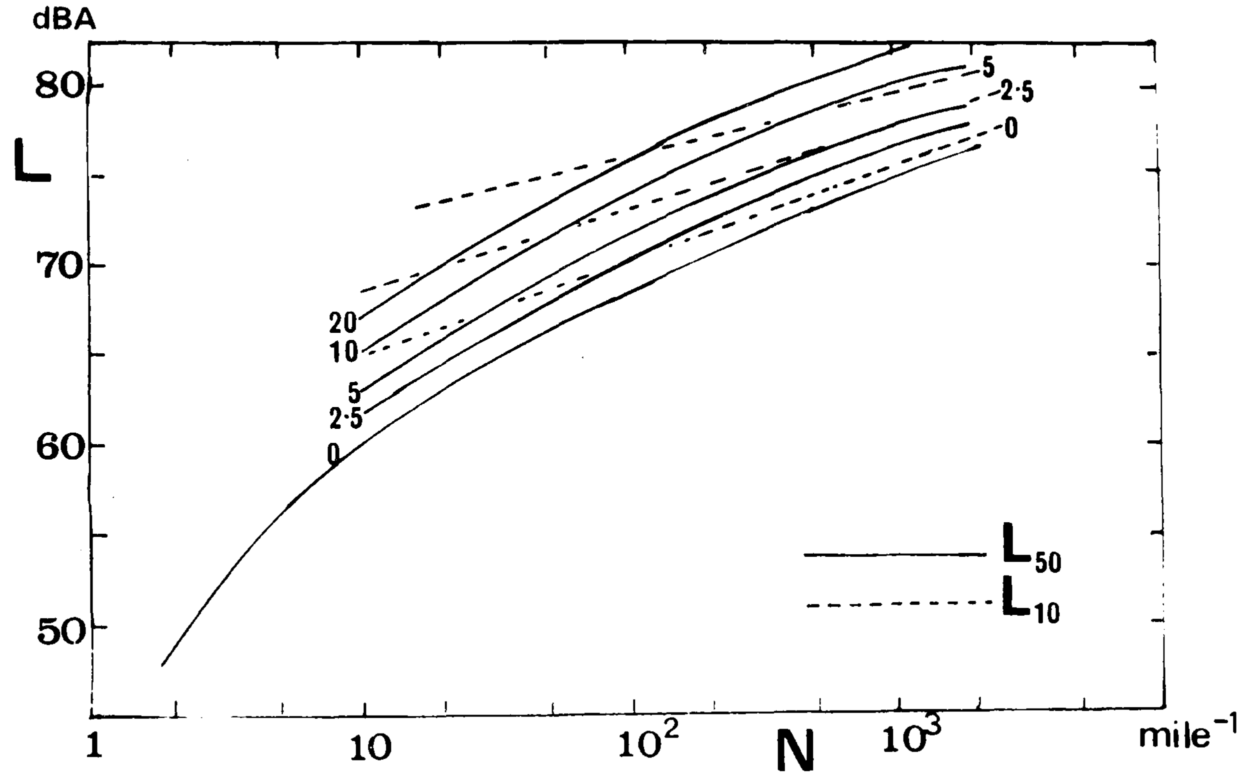


Fig. 6.8 Variation of L_{50} and L_{10} with number N of vehicles per mile for d = 100 ft. and different percentages of heavy vehicles, as indicated (after Galloway et al (24)).

TABLE 6.1

PREDICTED VARIATIONS IN L_{10} and L_{50} FOR CHANGES IN TRAFFIC DENSITY Q, DISTANCE OF OBSERVERS d, MEAN VELOCITY v, AND PERCENTAGE OF HEAVY VEHICLES p.

(a) INCREASE IN L_{10}.

VARIATION	THEORETICAL PREDICTIONS			EMPIRICAL PREDICTIONS
	GALLOWAY ET AL (24)	KURZE (42, 43)	SCHOLES AND SARGENT (20)	DELANY (37)
	dBA	dBA	dBA	dBA
Q x 2	2	2.5	2.2	2.7
d x $\frac{1}{2}$	3.2	2.5	3.8*	3.1 (concrete) 4.4 (grass-land)
v x 2	-	--	10	4.9
p (av'ge) = 10%	7	9	Negligible Ø	1.2

* plus attenuation depending on height of observer, e.g. 6 dB/100 m for 1.5 m above ground

Ø empirical prediction.

(b) INCREASE IN L_{50}.

	THEORETICAL PREDICTIONS			EMPIRICAL PREDICTIONS
VARIATION	GALLOWAY ET AL (24)	KURZE (42, 43)	RATHÉ (33)/ JOHNSON AND SAUNDERS (36)	DELANY (37)
	dBA	dBA	dBA	dBA
Q x 2	2.3	3	3 to 6 depending on d	4.5
d x ½	3.8	3	3*	2.5 (concrete) 3.3 (grassland)
v x 2	6	-	9	3.9
p (av'ge) = 10%	4	8	0.5 Ø	0.9

* plus 1 dBA attenuation per 100 ft. (30 m) ground absorption.

Ø empirical prediction (Johnson and Saunders).

Theoretical predictions of the variations of both L_{10} and L_{50} with Q appear to be underestimated as compared with Delany's empirical data, especially with regard to L_{50}. Rathé's predicted value of L_{50} depends on the ratio d/s. Thus, for example, assuming a mean speed of 75 km hr^{-1}, equation 6.11 predicts an increase of L_{50} by only 3 dBA when Q increases from 1500 to 3000 hr^{-1} for d = 100 m. On the other hand, when d = 7.5 m, Delany's reference distance, an increase of 4.1 dBA is predicted. For smaller values of Q, i.e. < 780 hr^{-1}, equation 6.11(b) is applicable at positions close to the roadside for which there is an increase of 6 dBA for doubling of Q.

There is fair agreement between the theoretical predictions and Delany's experimental values for variations of both L_{10} and L_{50} with d. Discrepancies are seen for the effects of both speed and percentage of heavy vehicles.

The predicted increases of both L_{10} and L_{50} with speed are considerably in excess of those observed. Commenting on this, Delany, whilst accepting that peak noise levels for individual vehicles may increase by 9 dBA for doubling of speed, pointed out that both L_{10} and, more especially L_{50}, are below peak values (i.e. L_{max}) and thus increase at a lower rate. Furthermore, account must be taken of the fact that not all vehicles are driven at constant speed and, as shown by Harland (44) the rate of increase of peak noise level with speed is much less for accelerating vehicles than for those driven at constant speed; the noise from accelerating vehicles exceeds that for non-accelerating vehicles and thus tends to dominate the value of L_{10}. These factors will thus produce a lower increase in level with traffic speed than reported for isolated vehicles.

The ~~relationships between~~ increases of noise levels ~~and~~ with the compositions of heavy traffic as determined by Delany, Scholes, Sargent, Johnson and Saunders are very much less than those predicted by Galloway et al and Kurze. However, measurements by Stephenson and Vulkan in the London area have shown an increase of L_{10} by 9 dBA for a change of composition from 16 to 50 per cent of heavy goods vehicles and a private communication to Delany from MIRA have indicated an increase of L_{10} by 10 dBA for a rise in the percentage of heavy traffic from 0 to 55 per cent for a mean traffic speed of 80 km hr^{-1}.

It should be reiterated that Delany's work was confined to freely flowing traffic at comparatively high speeds under conditions considerably different from those existing in urban areas where speed limits are in operation and, in most cases, observed. A method of prediction of L_{10} developed by the author is given in the next chapter.

In conclusion it may be remarked that the theories based on random spacing of vehicles do not appear to correlate better with experimental observations in predicting the variations of L_{10} and L_{50} with d and Q than Rathé's theory which assumes uniform spacing.

CHAPTER 7

A NEW METHOD OF PREDICTING L_{10} FOR URBAN MAIN ROADS SUBJECTED TO SPEED LIMITS.

7.1 GENERAL CONSIDERATIONS

In the method developed here for predicting L_{10} on urban main roads a steady rate of flow is assumed, i.e. no acceleration and no overtaking. Numerous observations made in the investigations reported later (Chapter 8) on roads subjected to a speed limit of 30 m.p.h. (48 km hr^{-1}) at points removed from traffic hazards have indicated that these conditions may be regarded as being reasonably normal, although speeds exceeding 40 m.p.h. (60 km hr^{-1}) are not uncommon given favourable conditions. The prediction is confined to single carriageway roads, restricted to a speed limit of 30 m.p.h. although the effects of speeding will be considered. Conditions on dual-carriageway and unrestricted roads are somewhat different and are more akin to those discussed in Chapter 6.

The effects of noise from traffic rather than from individual vehicles are more effectively deduced by observations at a distance from the roadside (e.g. 10 m) and it is with these observations which we are mainly concerned, although the same theory, as will be shown later, can be used to predict noise levels at kerbside. Except when the traffic density is high, for which congestion begins to occur and for which the theory is not intended, it is generally found that, on the type of road considered, traffic flows along two lanes close to the centre line. For a typical road width of 10 m, the two lanes of traffic are usually centred at distances of 13 m and 17 m, respectively, from an observer placed 10 m from the roadside. Considering the centre line situated at a distance d of 15 m from the observer, we may regard the traffic, as a whole, as flowing effectively along this line. The errors made in this assumption for nearside and farside lanes can be shown from a consideration of equation 7.1 to be - 1 dBA and +1 dBA, respectively. Except when the rates of flow in the two lanes differ considerably from one another, these errors tend to cancel each other out. In most cases a mean speed v of 45 km hr^{-1} (28 m.p.h.) can be reasonably assumed, although there is a tendency for it to increase when the traffic density is low.

If we consider the traffic to consist of equally spaced point sources separated by an amount s, the sound level at the point of observation is given by equations 6.3 to 6.5. Now the level L, at any time t, exceeds L_{10}, the level exceeded for 10 per cent of the total time of observation, between the times $t = nT - T/20$ and $t = nT + T/20$, where $n = 0, \pm 1, \pm 2, \ldots$ etc. and $T = s/v$ is the time period between vehicles. Thus $L = L_{10}$ when $\cos(2\pi vt/s) = \cos 2\pi(n \pm 1/20) = 0.95$, i.e.

$$L_{10} = 10\log_{10}\frac{\pi}{sd}\left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - 0.95}\right] + L_{ref} + 20\log_{10} d_0 \qquad 7.1$$

i.e. $$L'_{10} = 10\log_{10}\frac{\pi}{sd}\left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - 0.95}\right] \qquad 7.1(a)$$

where $$L_{10} = L'_{10} + L_{ref.} + 20\log d_0 \qquad 7.1(b)$$

Fig. 7.1 shows how L'_{10} varies with traffic density $Q = v/s$ for $v = 45$ km hr^{-1}, for different values of d.

It should be remembered that in deriving the equation 7.1 it was assumed that s is constant. In practice this is not so; it will be shown later how L_{10} is affected by vehicles bunching together. However, any changes in L_{10} due to this phenomenon are small but the appropriate corrections to be applied where necessary to the final result will be derived, nevertheless.

7.2 EFFECTS OF DIFFERENT CLASSES OF VEHICLES

If all the vehicles under consideration comprised a single class for which there is a common value of L_{ref}, L_{10} can be predicted directly from equation 7.1. This, however, is rare and the following method takes into account traffic consisting of vehicles of different classes, each class having a characteristic value of L_{ref}.

From equations 6.3 and 6.6 the maximum level L_{max} is given by

$$L_{max} = 10\log_{10}\frac{\pi}{sd}\coth\frac{\pi d}{s} + L_{ref} + 20\log_{10}d_o \qquad 7.2$$

i.e.

$$L_{max} = 10\log_{10}\frac{\pi}{sd}\coth\frac{\pi d}{s} + L_o + 20\log_{10}d \qquad 7.2(a)$$

where $L_o = L_{ref} + 20\log(d/d_o)$. Here L_o is the value of L_{max} when the stream consists only of one vehicle. The relationships

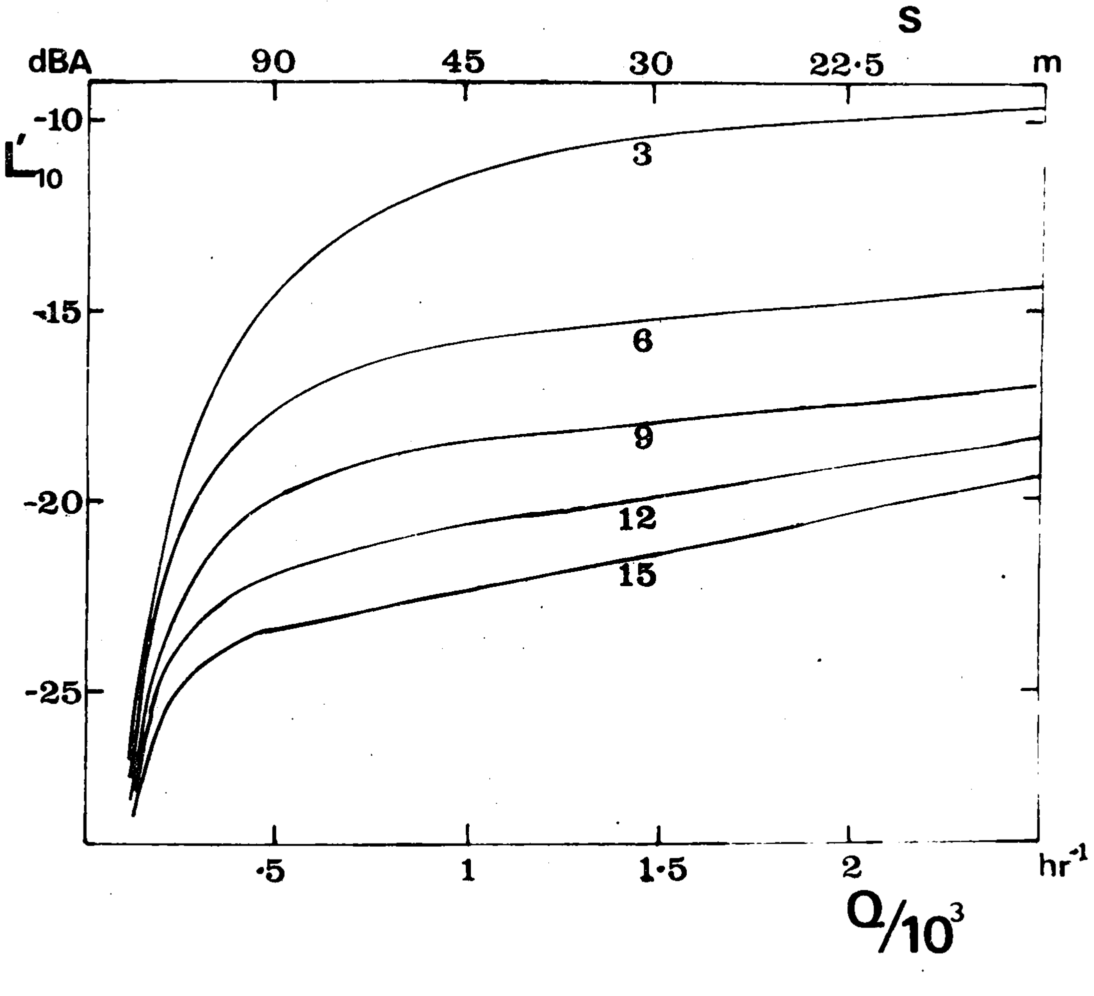


Fig. 7.1 Variations of L'_{10} with traffic flow Q, and spacing s, for a mean speed v = 45 km hr^{-1}, in accordance with equation 7.1 (a). Numerals indicate values of d in metres.

between $L_{max} - L_0$ and Q for d = 15, 6, and 3 m are shown in Table 7.1. For low traffic densities, i.e. $s \gg d$, coth $(\pi d/s)$ approaches $s/\pi d$ and

$$L_{max} \rightarrow 10\log_{10}\frac{1}{d^2} + L_0 + 20\log_{10} d = L_0 \qquad 7.2(b)$$

For d = 15 m, it can be seen that an error of less than 0.5 dBA is incurred by applying equation 7.2(b) when $Q < 500$ hr^{-1} and v = 45 km hr^{-1}.

Having established a relationship between L_{max} and L_0 we can now determine the noise level from a stream of vehicles by studying the sound propagation from a single vehicle from each class within the stream.

For a given vehicle for which $L_{max} = L_0$, at any time t we have (cf. equation 6.1).

$$\frac{I}{I_0} = \frac{d^2}{d^2 + (vt)^2} = \frac{1}{1 + (vt/d)^2}$$

i.e.

$$L_0 - L = 10\log_{10}\left[1 + (vt/d)^2\right] \qquad 7.3$$

Fig. 7.2 shows the relationships between L_0-L and t for different values of d as given by this equation. When the traffic density is sufficiently low, the upper parts of the peaks shown in Fig.6.2 are characteristic only of the single vehicle closest to the observer, at a given time, and unaffected by the effects of other vehicles, so that $L_0 \rightarrow L_{max}$ (see equation 7.2(b)). Under these circumstances each curve shown in Fig.7.2 may be taken to correspond to one half of a peak of the curve given in Fig. 6.2.

To measure L_{10} for a single class of vehicle we therefore

TABLE 7.1

RELATIONSHIPS BETWEEN $L_{max} - L_o$ AND Q FOR DIFFERENT VALUES OF d FOR $v = 45$ km hr^{-1} IN ACCORDANCE WITH EQUATION 7.2(a)

Q	$L_{max} - L_o$		
	d = 15 m	d = 6 m	d = 3 m
hr^{-1}	dBA	dBA	dBA
100	0	0	0
200	0	0	0
300	0.1	0.1	0
400	0.2	0.1	0
500	0.3	0.1	0
750	0.8	0.2	0
1000	1.3	0.3	0.1
1250	1.8	0.4	0.1
1500	2.3	0.6	0.1
2000	3.3	0.9	0.2
2500	4.2	1.3	0.4

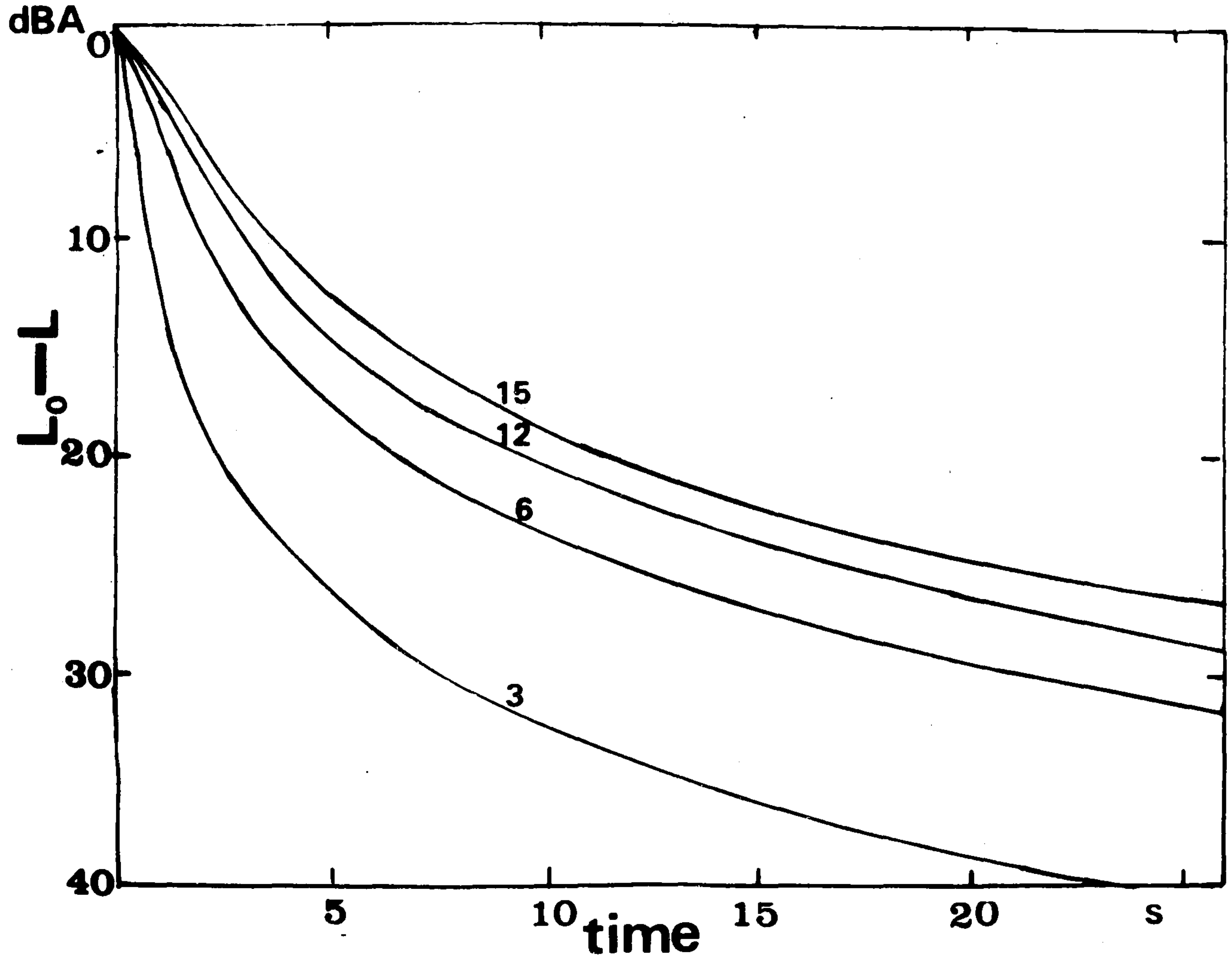


Fig. 7.2 Relationships between L_o-L and t in accordance with equation 7.3 where v = 45 km hr^{-1}. Numerals indicate values of d in metres.

measure the sound level on the curve of Fig 7.2 for which $t = T/20$, where the average time period T between successive vehicles is equal to $1/Q$. If T is measured in seconds and Q in hr^{-1} we find that $L = L_{10}$ when $t = 3600/(20\ Q) = 180/Q$ sec. For higher traffic densities we must take into account the effects of noise from other traffic and L_0 is replaced by L_{max} in accordance with equation 7.2(b), with the aid of Table 7.1.

To measure L_{10} when we have more than one class of vehicle the following procedure is adopted. Let there be a total of n classes for which the values of L_{max} are $(L_{max})_1$, $(L_{max})_2$, ... $(L_{max})_n$ and the corresponding rates of flow per hour, Q_1, Q_2, ..., Q_n. The total rate of flow is then given by

$$Q = \sum_{k=1}^{n} Q_k \qquad 7.4$$

If we assume that $(L_{max})_1 > (L_{max})_2 > \ldots\ldots > (L_{max})_n$, for a sufficiently high value of Q_1, the overall value of L_{10} may depend only on the noise emitted from the vehicles in class 1, which would constitute the loudest, and be independent of the noise from the vehicles in the other classes. Taking a typical case where $(L_{max})_1 - (L_{max})_2 = 10$ dBA, we see from Fig. 7.2 that a time of 3.6 s is taken for a drop by this amount, i.e. the level exceeds $(L_{max})_1 - 10$ dBA for each vehicle in this class for 7.2 s. Thus for 10 per cent of one hour, i.e. 360 s, this corresponds to the time of flow of $360/7.2 = 50$ vehicles. We see in this case that for $Q > 50\ hr^{-1}$, the value of L_{10} is determined only by the vehicles in class 1.

Let us now consider noise levels in descending intervals of say 2.5 dBA, e.g. 80, 77.5, 75 ... etc. dB, this being consistent with an instrumental error of ~~0.9~~ 1 dBA of the sound level meter (see Section 8.1.2). For each class of vehicle the time in seconds during which the level under consideration is exceeded is determined, applying the correction factor $L_{max} - L_o$ where necessary. Thus if the level L_k dBA is exceeded by a time $(t_k)_1$ seconds for a vehicle in class 1 and the corresponding rate of flow is Q_1 hr^{-1}, the number of seconds per hour which this level is exceeded by all vehicles in this class is given by $Q_1(t_k)_1$. Taking into account the vehicles in the remaining classes for which the corresponding times and rates of flow are $(t_k)_2$, $(t_k)_3$ .... $(t_k)_n$ and Q_2, Q_3 .... Q_n, respectively, the total number T of seconds per hour during which the level L_k is exceeded is

$$T_k = \sum_{s=1}^{n} Q_s (t_k)_s \qquad . \qquad 7.5$$

where n is the number of classes of vehicles. Values of T_k are calculated for $k = 1, 2, 3 .... m$ for which $L_1 - L_2 = L_2 - L_3 = ... = L_{m-1} - L_m \approx 2.5$ dBA. The computation ceases when T_n exceeds one tenth of one hour, i.e. 360 s, for which

$$T_{m-1} < 360 < T_m$$

L_{10} is determined by linear interpolation between L_{m-1} and L_m

i.e. $$L_{10} = L_m + \frac{2.5(T_m - 360)}{T_m - T_{m-1}} \text{ dBA} \qquad 7.6$$

Strictly speaking, because the noise level distribution with the number of seconds is Gaussian, the values of T_{m-1} and

T_m corresponding to L_{m-1} and L_m should be plotted on probability paper and a straight line drawn to determine the value of L_{10}. However, for a difference in levels of only 2.5 dBA, any error caused by assuming a linear distribution is small, most certainly less than 0.5 dBA.

7.3 APPLICATION OF METHOD

Consider the following example in which the traffic on a road is assumed to consist of two classes of vehicle, i.e. heavy and light, travelling at a mean speed of v of 45 km hr^{-1}, the observer being stationed at a distance $d = 15$ m from the centre line of the road. The respective maximum levels for single vehicles are $L_{o1} = 80$ dBA and $L_{o2} = 70$ dBA and the corresponding rates of flow are $Q_1 = 50\ hr^{-1}$ and $Q_2 = 2000\ hr^{-1}$. The corrections $L_{max}-L_o$, as obtained from Table 7.1,corresponding to these values of Q are 0 and 3.3 dBA, respectively. These give the maximum levels for the classes as $(L_{max})_1 = 80$ dBA and $(L_{max})_2 = 73.3$ dBA. Values of L_k, $(t_k)_1$, $[Q_1\ (t_k)]$, $(t_k)_2$, $[Q_2(t_k)_2]$ and T are displayed in Table 7.2 from which one sees that the value of L_{10} is 74.5 dBA.

Had Q_1, instead,been 100 hr^{-1}, the value of T_k for which $L_k = 75$ dBA would have been 360 s, giving a value of $L_{10} = 75$ dBA. One sees that there is no contribution from class 2 vehicles, for which $L_{max} = 73.3$ dBA, to this level and, here, L_{10} depends only on the noise emitted from the heavy traffic. In this case L_{10} could have been predicted directly from equation 7.1.

TABLE 7.2

CALCULATION OF L_{10}

L_{o1} = 80 dBA

L_{o2} = 70 dBA

d = 15 m

Q_1 = 50 hr^{-1}

Q_2 = 2000 hr^{-1}

v = 45 km hr^{-1}

$(L_{max})_1$ = 80 dBA $(L_{max})_2$ = 73.3 dBA.

L_k	$(t_k)_1$	$Q_1(t_k)_1$	$(t_k)_2$	$Q_2(t_k)_2$	T_k
dBA	s	s	s	s	s
77.5	2.2	110	0	0	110
75	3.6	180	0	0	180
72.5	5.0	250	0.8	1600	1850

$$\therefore L_{10} = 72.5 + \frac{1850 - 360}{1850 - 180} \times 2.5 = 74.5 \text{ dBA}$$

One might at first suppose that the value of L_{10} is affected by an increase in noise level caused by vehicles passing one another in opposite directions in front of the observer. The following example illustrates that this is not the case. Let there be a flow of vehicles of a single class, for which $L_o = 70$ dBA, totalling 2000 hr^{-1} of which 1000 hr^{-1} each pass in opposite directions. The values of L_{max} corresponding to flows of 1000 hr^{-1} and 2000 hr^{-1} are given by Table 7.1, for $d = 15$ m, as 71.3 and 73.3 dBA, respectively. Now when vehicles having equal values of L_{max} pass one another in front of the observer there is an increase in level to about $L_{max} + 3$ dBA and considering the extreme case of all vehicles passing one another in this position we have effectively 1000 vehicles per hour of level $71.3 + 3 = 74.3$ dBA. From Fig. 7.2 and Table 7.1 we see that L_{10} in this instance is 73.6 dBA. Taking the other extreme case where there is no crossing of vehicles in front of the observer we have, effectively, $Q = 2000$ hr^{-1} for which $L_{max} = L_{10} = 73.3$ dBA. Thus the maximum effect of this phenomenon is to raise L_{10} by only 0.3 dBA.

However, we have not considered that some of the noise from the vehicles in the farside lane is shielded by the vehicles in the nearside lane. This will nullify any predicted increase in level. One can thus safely disregard the effects of passing vehicles. A similar argument may be applied to overtaking, a comparatively rare event, although it should be pointed out that an increase in noise level may arise from higher speeds and the effects of accelerations.

7.4. EFFECTS OF SPEED

Although the roads under consideration are subjected to 30 m.p.h. speed limits it is not uncommon to find traffic flowing in excess of this limit, often at speeds of 60 km hr^{-1} (40 m.p.h.) when conditions permit. On the other hand, especially when much heavy traffic is present, the average speed may fall as low as 40 km hr^{-1} (25 m.p.h.).

Because the value of s in equation 7.1 changes with v, the variation of L'_{10} with Q must be a function of v. Fig.7.3 shows these variations, in accordance with equation 7.1, for different values of v. Furthermore, the value of L_{ref}, and hence L_o, for a single vehicle also varies with v. According to Harland (44) this is given by

$$(L_{ref})_1 - (L_{ref})_2 = 30 \log_{10} \frac{V_1}{V_2} \qquad 7.7$$

It can be seen that a change in speed from 45 to 60 km hr^{-1} results in an increase in L_{ref} and hence, L_o, by 3.7 dB. Thus when the average speed of traffic is higher one must take into consideration, for a given value of Q, a decrease in L'_{10} together with an increase in L_{ref}, and of L_o. Table 7.3 shows how $L_{max} - L_o$ varies with Q in accordance with equation 7.2(a) for average speed v varying from 40 to 65 km hr^{-1}, where d = 15 m.

Figure 7.4 shows the relationships between L_o-L and t for d = 15 m for different values of v.

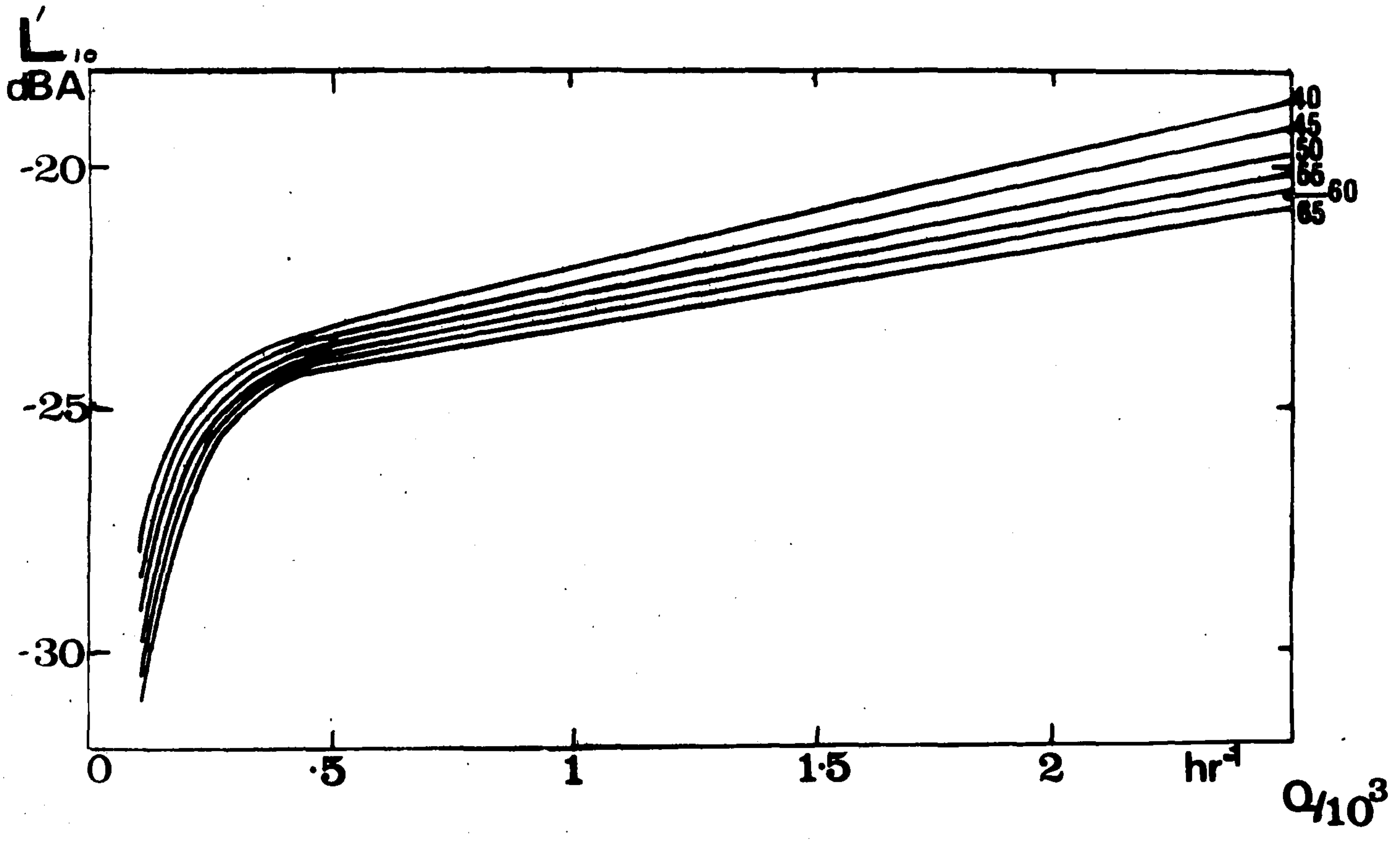


Fig 7.3 Variations of L'_{10} with Q for different values of v in accordance with equation 7.1(a) where d = 15 m. The figures indicate values of v in km hr^{-1}.

TABLE 7.3

RELATIONSHIPS BETWEEN $L_{max} - L_o$ AND Q FOR DIFFERENT VALUES OF v, FOR d = 15 m IN ACCORDANCE WITH EQUATION 7.2(a)

Q	$L_{max} - L_o$					
	v = 40 km hr^{-1}	v = 45 km hr^{-1}	v = 50km hr^{-1}	v = 55 km hr^{-1}	v = 60 km hr^{-1}	v = 65 km hr^{-1}
hr^{-1}	dBA	dBA	dBA	dBA	dBA	dBA
100	0	0	0	0	0	0
200	0.1	0	0	0	0	0
300	0.2	0.1	0.1	0.1	0.1	0.1
400	0.3	0.2	0.2	0.1	0.1	0.1
500	0.4	0.3	0.3	0.2	0.2	0.2
750	0.9	0.8	0.6	0.6	0.4	0.4
1000	1.5	1.3	1.0	0.9	0.8	0.7
1250	2.1	1.8	1.5	1.3	1.1	1.0
1500	2.7	2.3	2.0	1.7	1.5	1.4
2000	3.8	3.3	3.0	2.6	2.3	2.1
2500	4.7	4.2	3.8	3.4	3.1	2.8

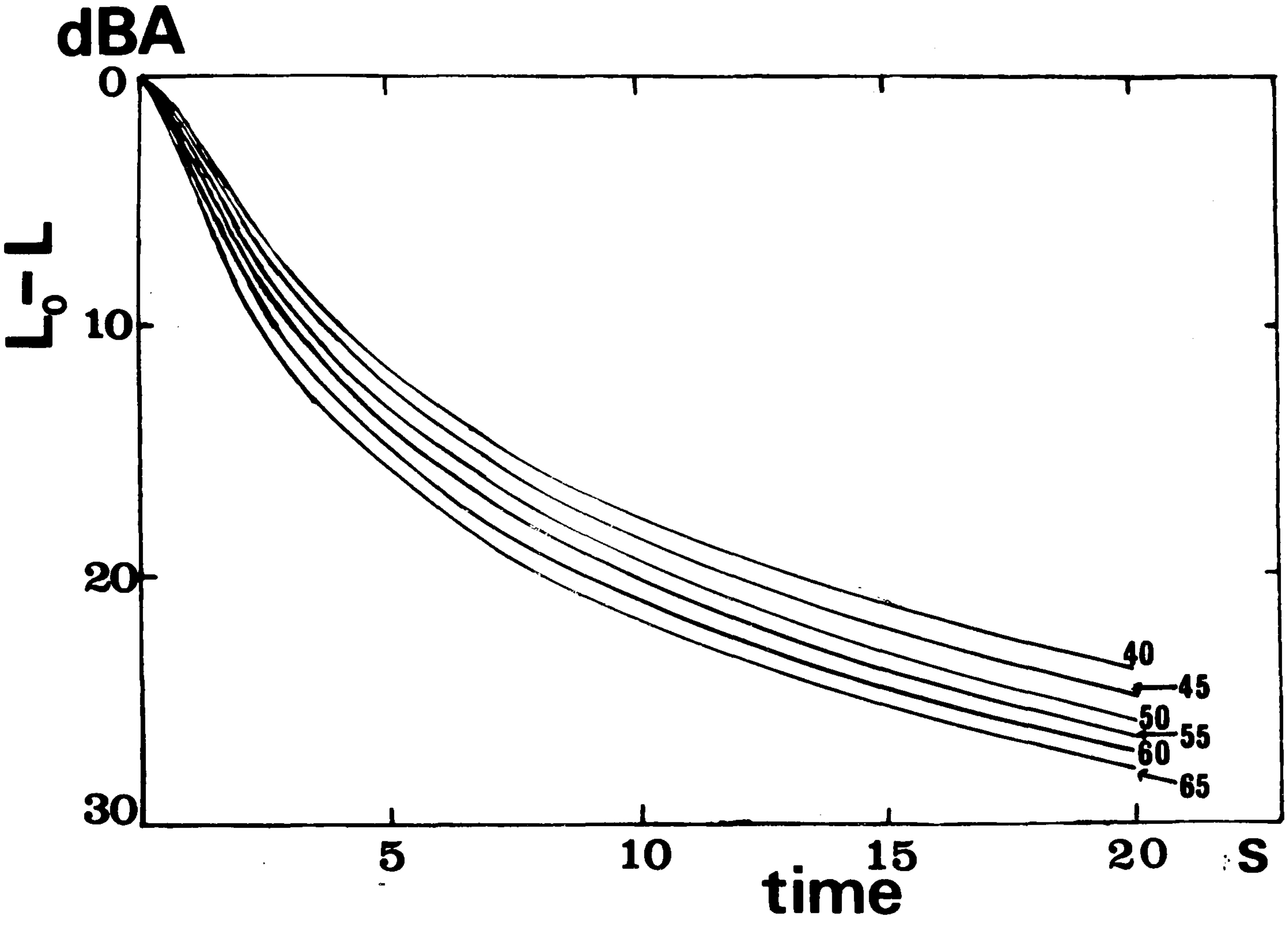


Fig. 7.4 Relationships between L_o-L and t in accordance with equation 7.3 for different values of v, where d = 15 m. The figures indicate values of v in km hr^{-1}.

7.5 EFFECTS OF GROUPING

It has been assumed so far that the vehicles are equally spaced apart, a phenomenon which, of course, is not met with in practice. However, provided that the spacing is sufficiently large that overlapping of the peaks of Fig.7.2 for individual vehicles takes place at levels below that for L_{10}, the computed value of L_{10} is not affected in any way. On the other hand, when the observer is at some distance from the kerbside (e.g. d = 15 m), the peaks for individual vehicles become less sharp and overlapping is more likely to occur at levels above L_{10}, especially for high traffic densities.

Numerous observations have shown that vehicles often travel in a nose-to-tail manner and Table 7.4 summarises the results of these observations by indicating the mean percentages of vehicles moving in groups of twos, threes, fours and fives. It is seen that these percentages decrease with increasing group size in a roughly exponential manner.

These groups may be treated as individual vehicles although they cannot be regarded as point sources but arrays of point sources. At a speed of 45 km hr^{-1}, the spacing may be less than two vehicles for private cars and only one vehicle for lorries. A realistic and convenient distance between centres of neighbouring vehicles in a group is 12.5 m and Fig. 7.5 shows curves representing calculated relationships between $L-L_0$ and t for the motion of arrays of 2, 3, 4, and 5 point sources spaced apart by this distance for d = 15 m. Similar curves for a speed of 60 km hr^{-1}, for which a distance of separation of 15 m between centres of adjoining groups, are shown in Fig. 7.6.

TABLE 7.4

AVERAGE PERCENTAGES OF VEHICLES PROCEEDING IN GROUPS.

NUMBER IN GROUP	1	2	3	4	5
PERCENTAGES OF VEHICLES	54	26	11	6	3
AVERAGE NUMBER OF GROUPS PER 100 VEHICLES.	54	13	4	1.5	0.6

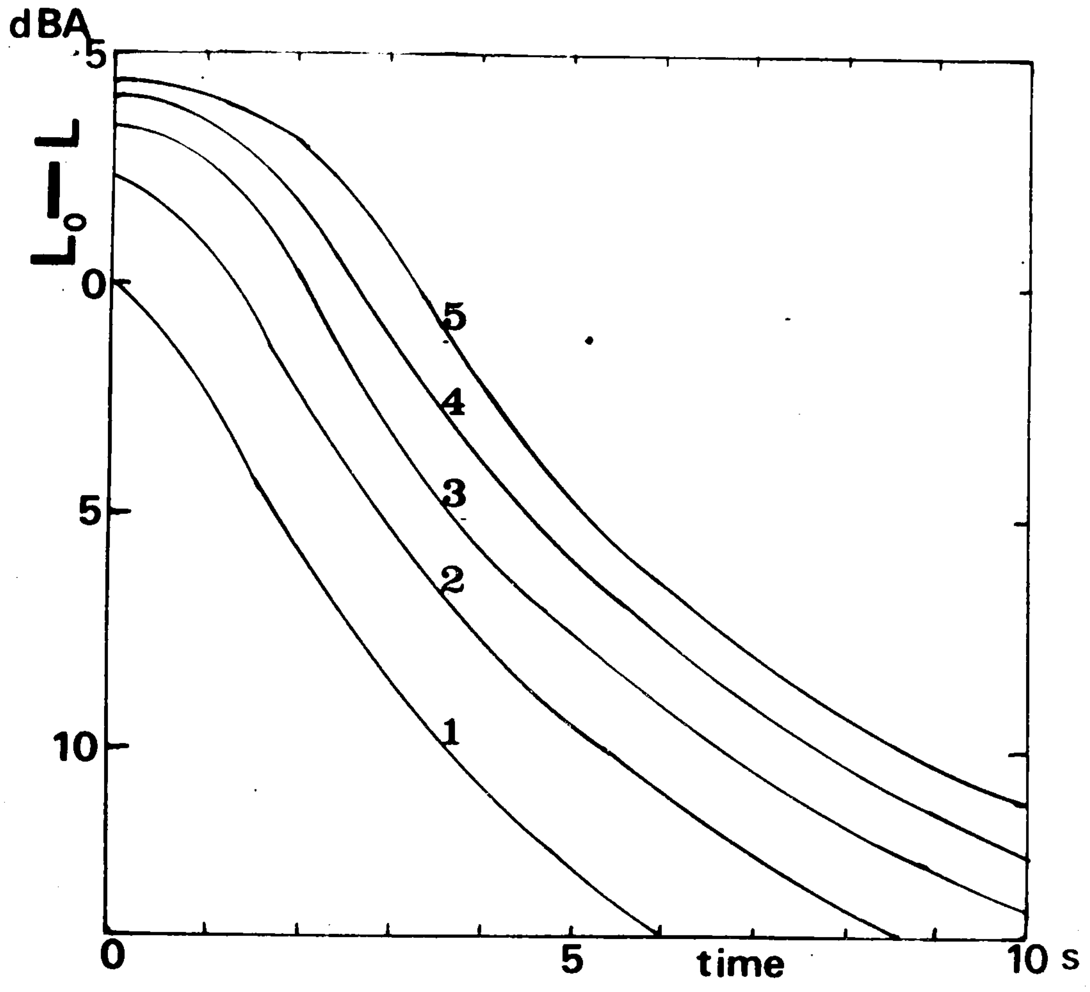


Fig. 7.5 Relationships between L_o-L and t for groups of 1, 2, 3, 4 and 5 vehicles when v = 45 km hr^{-1}.

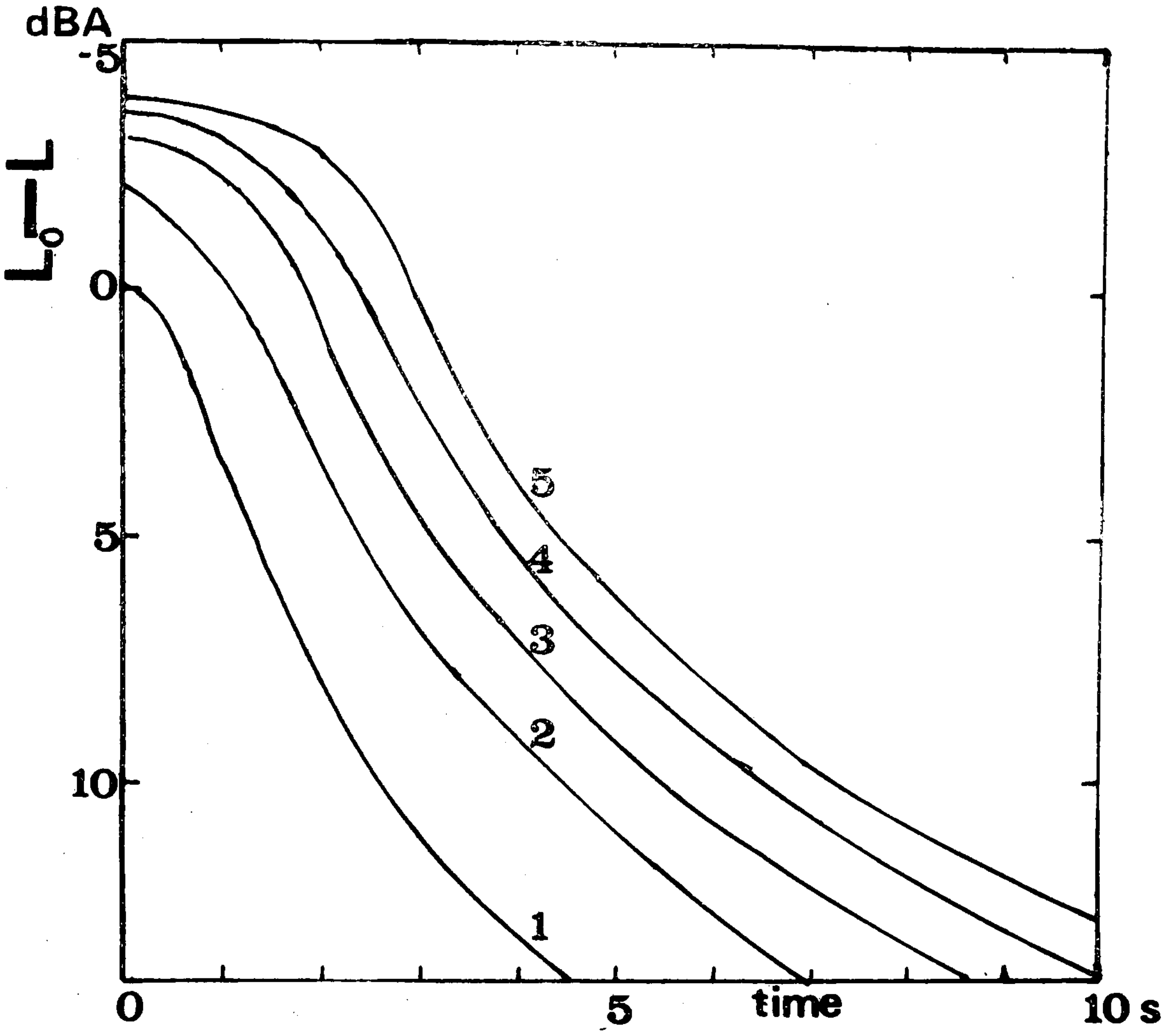


Fig. 7.6 Relationship between L_o-L and t for groups of 1, 2, 3, 4 and 5 vehicles when v = 60 km hr^{-1}.

Consider the example of a stream of traffic consisting of a single class of vehicle, e.g. cars only, for which the peak value L_o for an individual vehicle is 70 dBA at $d = 15$ m when $Q = 1000$ hr^{-1}. From Table 7.4 and Fig. 7.5 we can enumerate five classes of vehicle for which $Q_1 = 540$ hr^{-1}, $Q_2 = 130$ hr^{-1}, $Q_3 = 37$ hr^{-1}, $Q_4 = 15$ hr^{-1} and $Q_5 = 6$ hr^{-1} and the corresponding peak levels are given by $L_{o_1} = 70.3$ dBA, $L_{o_2} = 72.3$ dBA, $L_{o_3} = 73.3$ dBA, $L_{o_4} = 74.0$ dBA and $L_{o_5} = 74.4$ dBA. Using the procedure described earlier we find that $L_{10} = 72$ dBA which is 0.5 dBA higher than if the effects of grouping were disregarded. One should, of course, have considered two additional classes of vehicle, representing groups of six and seven vehicles, respectively, for which $Q_6 = 2$ hr^{-1} and $Q_7 = 1$ hr^{-1} but their effects on L_{10} can easily be shown to be negligible.

Table 7.5 enumerates the corrections to be made to L_{10} for a single class of vehicle to allow for grouping. Although this phenomenon increases the peak noise level, the total time during which the higher levels persist is reduced. The second factor appears to predominate for both high and low traffic densities whereas the first becomes more effective for traffic densities of the order of 1200 to 1500 per hour. Except for average speeds greater than 55 km hr^{-1}, the effect of grouping is negligible when Q is less than 500 hr^{-1}. It is quite usual on main urban roads for the value of L_{10} to be determined only by the number of heavy lorries. Unless this number is large, when in any case a reduction of average speed is likely, no

TABLE 7.5

CORRECTIONS TO L_{10} WHEN d = 15 m, FOR A SINGLE CLASS OF VEHICLE, TO ALLOW FOR GROUPING, TAKING VARIATIONS OF v INTO ACCOUNT.

Q hr^{-1} OR H v km hr^{-1}	100	200	300	400	500	750	1000	1250	1500	2000	2500
40	0	0	0	0	0	0	+0.5	+1	+1	0	-1
45	0	0	0	0	0	+0.5	+0.5	+1	+1	0	-1
50	0	0	0	0	0	+0.5	+0.5	+0.5	+0.5	0	-1
55	-0.5	0	0	0	+0.5	+0.5	+0.5	+0.5	+0.5	0	-0.5
60	-1	0	0	+0.5	+0.5	+0.5	+0.5	+0.5	+0.5	0	-0.5
65	-1	-0.5	0	+0.5	+0.5	+0.5	+0.5	+0.5	+0.5	0	0

correction is required. Even when a correction is necessary it is small and can often safely be neglected.

7.6 RESULTS

Table 7.6 provides calculated values of L_{10} for d = 15 m and v = 45 km hr^{-1} for two classes of vehicle for which the difference in reference levels is 10 dBA. In column 1 of this table we see that the effect of vehicles grouping together is for L_{10} to be independent of Q for high rates of flow, where the effects of a single class of vehicle predominates.

The following relationships describe the behaviour of L_{10} with varying rates of flow for d = 15 m and v = 45 km hr^{-1}.

For $H < 50\ hr^{-1}$ or Q/25 whichever is the greater

$$L_{10} = L_{o2} - 0{\cdot}7 + Q/500 - \log_{10}^{-1}(1 - Q/270) + 10H/Q + K_1 \text{ dBA} \qquad 7.8$$

Assuming that $L_{o1} - L_{o2} = 10$ dBA

For $H \geqslant 50\ hr^{-1}$ or Q/25 whichever is the greater

$$L_{10} = L_{o1} - 1 + H/500 - \log_{10}^{-1}(1 - H/270) + K_2 \text{ dBA} \qquad 7.9$$

assuming that $L_{o1} - L_{o2} \geqslant 10$ dBA.

Here L_{o1} = peak level for individual heavy vehicles.

L_{o2} = peak level for individual light vehicles.

Q = total number of vehicles flowing per hour.

H = number of heavy vehicles flowing per hour.

K_1 = correction due to grouping, dependent on Q (see Table 7.5).

K_2 = correction due to grouping, dependent on H (see Table 7.5).

TABLE 7.6

PREDICTIONS OF L_{10} FOR URBAN MAIN ROADS $d = 15$ m, $v = 45$ km hr^{-1}, $L_{o_1} - L_{o_2} = 10$ dBA.

CORRECTED FOR GROUPING FROM TABLE 7.5.

TRAFFIC DENSITIES	NOISE LEVELS $L_{10} - L_{o2}$ FOR DIFFERENT PERCENTAGES OF HEAVY VEHICLES					
Q	0%	10%	20%	30%	40%	50%
hr^{-1}	dBA	dBA	dBA	dBA	dBA	dBA
100	-6	-3.5	-2.5	-1.5	-1	0
200	-2	-1	0	1.5	3.5	5
300	-0.5	0	1.5	4.5	6	7
400	0	1	4	6	7.5	8
500	0	2.5	5	7	8	8.5
750	1	3	7	8	8.5	9.5
1000	2	5	8	8.5	9	10
1250	3	6	8.5	9	9.5	10.5
1500	3.5	7	9	9.5	10	11
2000	3.5	8	9.5	10	11	12
2500	3.5	8.5	10	11	11.5	13

The above equations show that when $H \geqslant 50\ \mathrm{hr}^{-1}$, provided that the number of heavy vehicles is greater than 4 per cent of the total, L_{10} depends only on the <u>number</u> of heavy vehicles and not the <u>percentage</u> and is independent of the rate of flow of light vehicles.

Table 7.7 shows calculated values of L_{10} for $d = 15$ m and $v = 60\ \mathrm{km\ hr}^{-1}$ for two classes of vehicle for which the difference in reference level is again 10 dBA. Here we must take into account the effects of speed in accordance with equation 7.7 and we now have that the peak levels for heavy and light traffic respectively are raised by 3.7 dBA. Allowance has again been made for grouping of vehicles.

When considering average traffic speeds other than $45\ \mathrm{km\ hr}^{-1}$ equations 7.8 and 7.9 are no longer valid and the following relationships become applicable:

For $\underline{H < 50\,[1 + 3.36 \log_{10} (v/45)]}$ or $Q/25$, whichever is the greater

$$L_{10} = L_{02} - 0{\cdot}7 + 9Q/100V + 30 \log_{10} (V/45) + 10H/Q - \log_{10}^{-1} \left[1 - Q/\{270 + 640 \log_{10} (V/45)\} \right] + K_1 \ \mathrm{dBA} \qquad 7.8(a)$$

Assuming that $L_{01} - L_{02} = 10$ dBA.

For $\underline{H \geqslant 50\,[1 + 3.36 \log_{10} (v/45)]}$ or $Q/25$, whichever is the greater

TABLE 7.7

PREDICTIONS OF L_{10} FOR URBAN MAIN ROADS

$d = 15$ m, $v = 60$ km hr^{-1} $L_{o1} - L_{o2} = 10$ dBA.

Corrected for grouping from Table 7.5.

TRAFFIC DENSITIES Q	NOISE LEVELS $L_{10} - L_{o2}$ FOR DIFFERENT PERCENTAGES OF HEAVY VEHICLES					
	0%	10%	20%	30%	40%	50%
hr^{-1}	dBA	dBA	dBA	dBA	dBA	dBA
100	-4.5	-2	-1.5	-1	-1	+2
200	+0.5	+1	+1.5	+3	+5	+6.5
300	+1.5	+3	+3.5	+5.5	+7	+8.5
400	+3	+3.5	+4.5	+7	+9	+10.5
500	+3.5	+4	+6	+8.5	+10.5	+11
750	+4	+4.5	+9	+10.5	+11.5	+12
1000	+4.5	+6	+10.5	+11.5	+13	+14
1250	+5	+8	+11	+12	+13.5	+14
1500	+5.5	+9	+11.5	+13	+14	+14.5
2000	+6	+10.5	+13	+13.5	+14	+14.5
2500	+6	+11	+14	+14	+14.5	+15

$$L_{10} = L_{01} - 1 + 9H/100v + 30\log_{10}(v/45) - \log_{10}^{-1}[1 - H/\{270 + 640\log_{10}(v/45)\}] + K_2 \text{ dBA} \qquad 7.9(a)$$

assuming that $L_{01} - L_{02} \geq 10$ dBA. Here L_{01} and L_{02} are the peak levels at 45 km hr^{-1}.

The above relationships were derived simply from calculated values of L_{10} such as those given in Tables 7.6 and 7.7. The curves describing them are essentially exponential in form, for lower values of Q and straight lines for higher values. For values of $L_{01} - L_{02}$, other than 10 dBA, the above equations should be modified accordingly.

When correcting for grouping of vehicles using Table 7.5 the predominant class of traffic is taken into consideration. If neither class of traffic predominates the the correction factor should be interpolated between K_1 and K_2.

7.8 APPLICATION TO KERBSIDE OBSERVATIONS

The method of prediction given here can also be applied to kerbside observations. One can no longer assume that all vehicles proceed along the centre line of the road, because of the comparatively large differences in distance between the two lanes; traffic proceeding in each direction must be considered separately and their effects combined.

We must now consider two separate values of d, e.g. d' = 3 m and d" = 6 m for a road 9 m in width. Putting d' = 3 m, the peak levels for single heavy and light vehicles taken to be 80 dBA and 70 dBA for d = 15 m are now increased to L'_{o1} = 94 dBA and L'_{o2} = 84 dBA, respectively, from the inverse square law, for which the corresponding traffic densities are Q_1' = 25 hr^{-1} and Q_2' = 1000 hr^{-1}, assuming densities of Q_1 = 50 hr^{-1} and Q_2 = 2000 hr^{-1} with equal rates of flow in either direction. For d" = 6 m the levels become L''_{o1} = 88 dBA and L''_{o2} = 78 dBA for which Q_1'' = 25 hr^{-1} and Q_2'' = 1000 hr^{-1}. Table 7.1 gives the corresponding values of L_{max} as $(L'_{max})_1$ = 94 dBA, $(L'_{max})_2$ = 84 dBA, $(L''_{max})_1$ = 88 dBA and $(L''_{max})_2$ = 78.2 dBA. Referring to Table 7.8 we see that L_{10} = 82.7 dBA. Even with a small percentage of heavy vehicles, the value of L_{10} is completely unaffected by the light traffic flowing in the farside lane. Because of the relative sharpnesses of the peaks for individual vehicles, with low values of d, the effects of grouping are negligible.

Table 7.9 compares predictions of kerbside observations with measurements of L_{10} conducted at 140 kerbside sites in urban roads in London by Stephenson and Vulkan (see also Fig.5.2). Because of the large number of measurements taken the overall effect of variations due to differences in speed, road width, and road surfaces were minimised. Very good agreement is obtained between predicted and experimental values of L_{10} except for higher densities of heavy traffic when $Q \geqslant 1500$ hr^{-1} where the theoretical values are up to 2 dBA higher than the measured values. The discrepancy is probably

TABLE 7.8

CALCULATION OF L_{10} FOR KERBSIDE OBSERVATIONS. $d' = 3m$, $d'' = 6m$

$v = 45$ km hr^{-1} $Q_1 = 50$ hr^{-1}

$Q_2 = 2000$ hr^{-1}

$L'_{o1} = 94$ dBA $L''_{o1} = 89$ dBA

$L'_{o2} = 84$ dBA $L''_{o2} = 78$ dBA

$(L'_{max})_1 = 94$ dBA $(L''_{max})_1 = 88.2$ dBA

$(L'_{max})_2 = 84$ dBA $(L''_{max})_2 = 78$ dBA

$Q_1' = Q_1'' = Q_{1/2}$

$Q_2' = Q_2'' = Q_2/2$

L_k	$(t_k)'_1$	$Q'_1(t_k)'_1$	$(t_k)'_2$	$Q'_2(t_k)'_2$	$(t_k)'_1$	$Q''_1(t_k)''_1$	$(t_k)''_2$	$Q''_2(t_k)''_2$	T_k
dBA	s	s	s	s	s	s	s	s	s
92.5	0.25	6	0	0	0	0	0	0	6
90	0.52	13	0	0	0	0	0	0	13
87.5	0.80	20	0	0	0.16	4	0	0	24
85	1.16	29	0	0	0.48	12	0	0	41
82.5	1.60	40	0.32	320	0.76	19	0	0	379

$$\therefore\ L_{10} = 82.5 + \frac{379 - 360}{379 - 41} \times 2.5 = 82.7 \text{ dBA}$$

TABLE 7.9

APPLICATIONS OF PREDICTIONS OF TRAFFIC NOISE FOR URBAN MAIN ROAD TO STEPHENSON AND VULKAN'S KERBSIDE MEASUREMENTS OF L_{10}.

Nearside $d' = 3$ m

heavy traffic, $L'_{o1} = 87.5$ dBA
light traffic, $L'_{o2} = 77.5$ dBA.

Far side $d'' = 6$ m

heavy traffic, $L''_{o1} = 81.5$ dBA
light traffic, $L''_{o2} = 71.5$ dBA.

Traffic Densities Q	Noise Levels L_{10}			
	Predicted		Measured	
	0% Heavy	20% Heavy	16% Heavy	16-20% Heavy
hr^{-1}	dBA	dBA	dBA	dBA
100	61	62.5	61	65.5
200	66.5	68	64	68
300	69	70	66.5	70
400	70	73	68.5	72
500	70.5	74.5	70	73.5
750	71.5	75.5	72.5	76
1000	72.5	76	73.5	77
1250	74	77.5	74.5	77.5
1500	74.5	78.5	75	77.5
2000	75.5	79.5	75.5	78
2500	76	80	76	78

due to a larger number of heavy vehicles moving at lower than average speeds, which is characteristic of conditions approaching congestion.

The values of the noise levels quoted in Table 7.8 are very much higher than those determined by Stephenson and Vulkan (Table 7.9). Stephenson and Vulkan conducted their investigations in 1967 when the levels were considerably lower than those observed in the present investigation. Vulkan, in a private communication, has indicated that he has recently repeated measurements at some of the sites used in his earlier investigation and has observed increased levels of traffic noise consistent with those quoted in Table 7.8.

CHAPTER 8.

OBJECTIVE MEASUREMENTS OF ROAD TRAFFIC NOISE.

8.1 INSTRUMENTATION

8.1.1 General Considerations

The following instruments were used for the objective measurements and analyses of road traffic noise.

(a) 2 Precision Sound Level Meters (B and K type 2206), fitted with ½ inch capacitor microphones (B and K type 4148), and supporting stands.

(b) 2 Sound Level Calibrators (B and K type 4230).

(c) 2 Portable Tape Recorders (Uher 4000 Report L and 4200 Report L Stereo).

(d) Audio Spectrometer (B and K type 2110).

(e) Level Recorder (B and K type 2305).

(f) Statistical Distribution Analyser (B and K type 4420).

(g) Gradiometer.

(h) Tally counters.

8.1.2 Precision Sound Level Meter (B and K type 2206)

The Precision Sound Level Meter (see Fig. 8.1) consists of a capacitor microphone (B and K ½ inch type 4148) coupled to an amplifier by means of an impedance matching device (B and K type UA 0208 adaptor). The microphone is polarised with a direct EMF of 28 V. The meter has a range of 20 dB and the

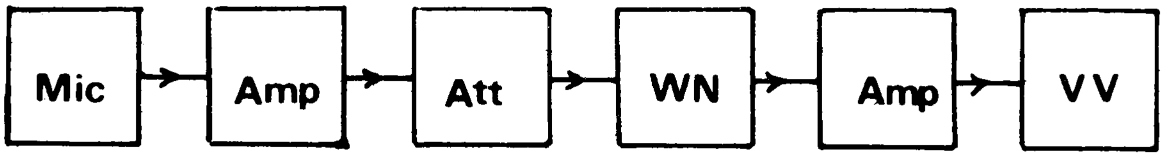


Fig. 8.1 Block diagram of Sound Level Meter.

MIC = microphone.

AMP = amplifier.

ATT = attenuator.

WN = weighting network.

VV = valve voltmeter.

attenuation can be switched in 10 dB stages and indications are given in dB above 20×10^{-6} N m^{-2}.

One of three weighting networks A, B, and C (8) is switched into the circuit to provide the required frequency response (Fig.8.2) and the reading of the instrument is expressed in either dBA, dBB or dBC, as appropriate. The networks are intended to correspond to the mean frequency responses of the normal human ear for sound levels of 40, 70 and 100 phons, respectively (see Fig. 2.1). However, for the reasons given in Chapter 4, only the A-weighting network was used for which a range of from 37 to 140 dBA re 20×10^{-6} N m^{-2} is obtainable.

The instrument is calibrated immediately before and after use by means of the Sound Level Calibrator (B and K type 4230) illustrated schematically in Fig. 8.3. It consists of a 1 kHz stabilised oscillator driving a piezoelectric "bender" type transducer which is attached to a membrane to produce a sound pressure at the coupler volume. The oscillations are also stabilised ~~mechanically~~ by means of a Helmholtz resonator. A temperature sensitive resistor built into the oscillator circuit provides temperature compensation of the calibrator. The manufacturers state in their handbook that variations due to changes in pressure are less than ± 0.05 dB per 100 mbar and those due to temperature changes are less than 0.05 dB, within the range from 10 to 30 deg. C. When the calibrator is placed in position over the microphone of the sound level meter (see Fig. 8.4) there is a sound pressure level of

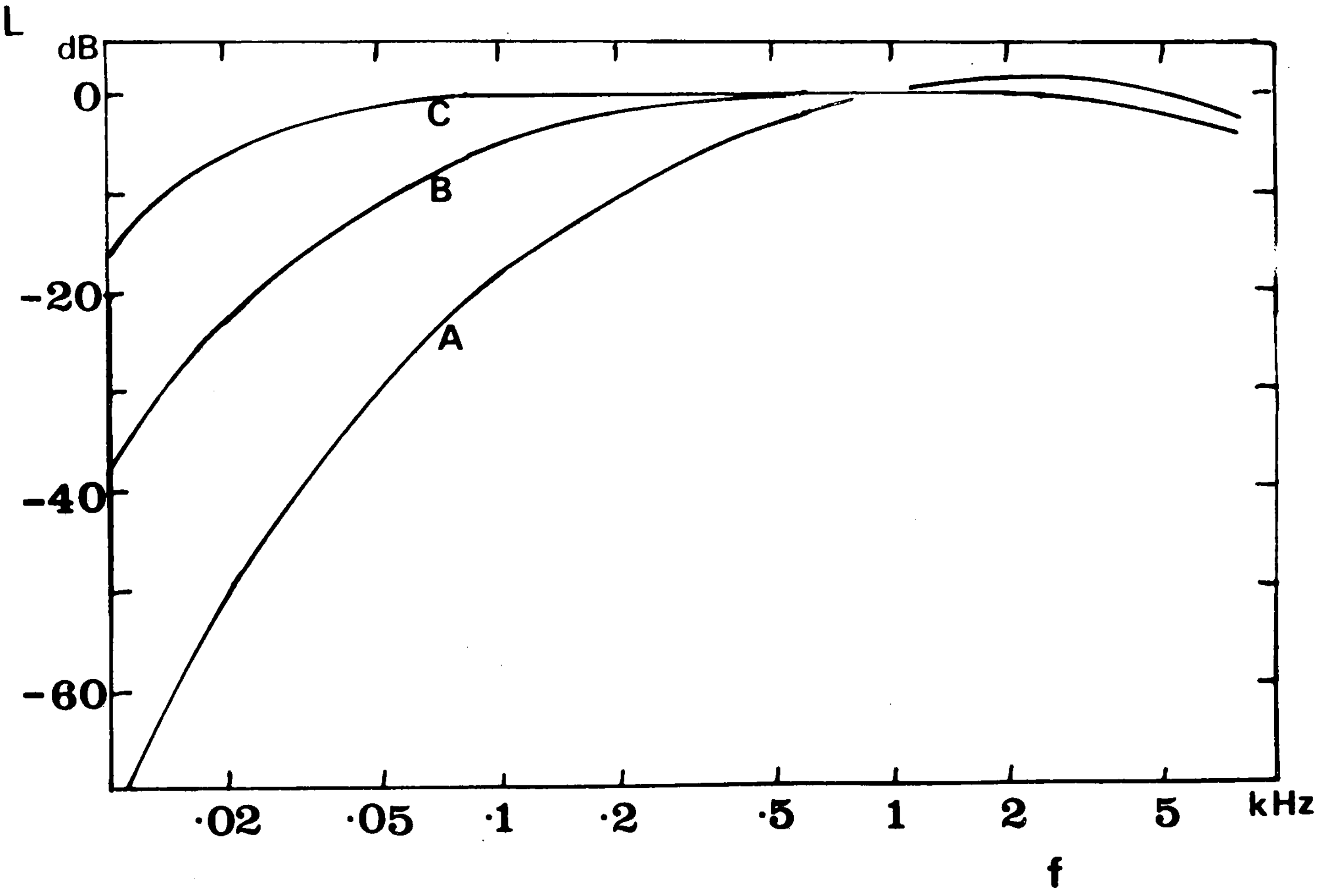


Fig. 8.2 Weighting networks of Sound Level Meter in accordance with IEC 179 and BS 4197, 1967.

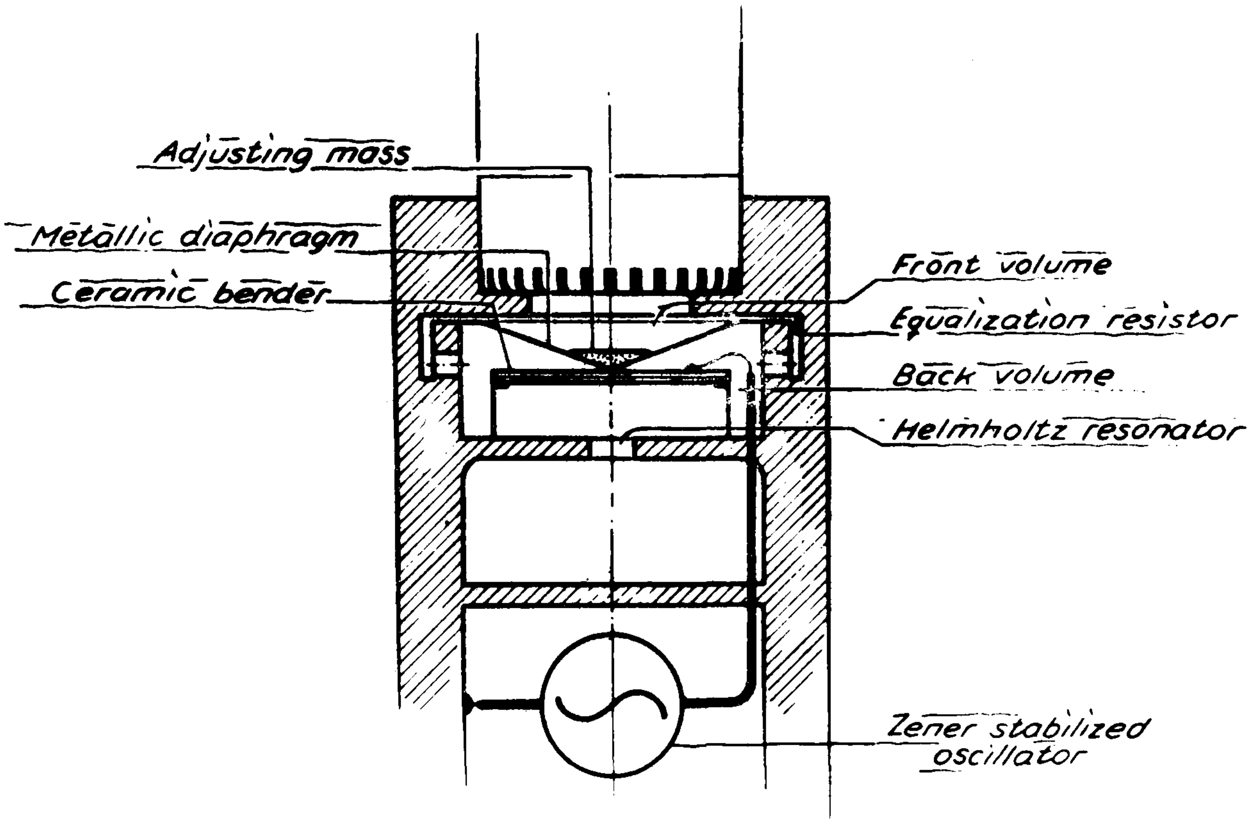


Fig. 8.3 Schematic diagram of B and K Sound Level Calibrator (Type 4230).

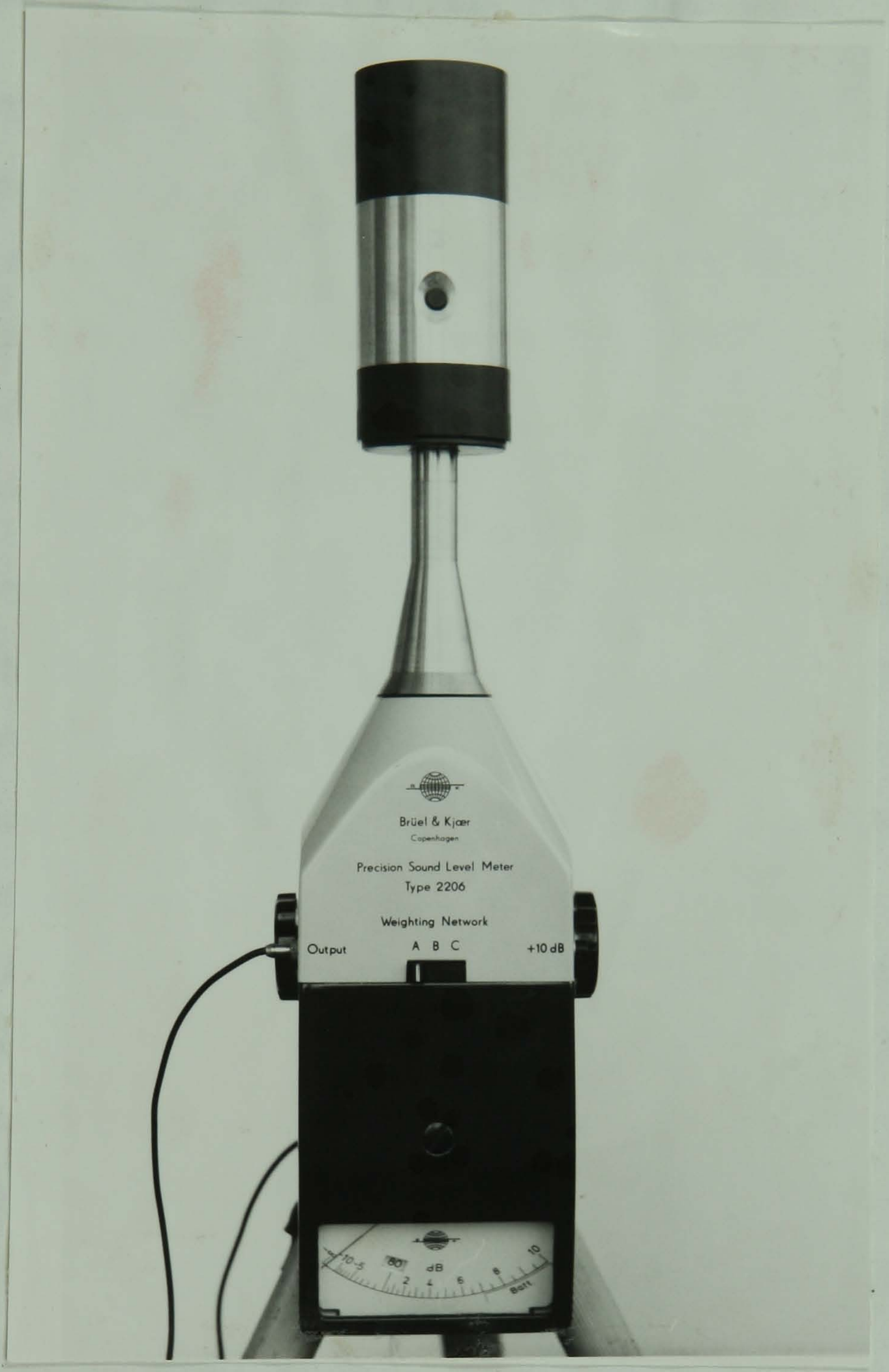


Fig. 8.4 Calibrator in position on microphone of Sound Level Meter.

94 ± 0.3 dB re 20×10^{-6} N m^{-2} at the diaphragm of the microphone. Because the operating frequency is 1000 Hz, the calibration is equally applicable to A, B and C weightings since the corresponding response curves intersect at this frequency.

The sound level meter is mounted on a tripod with the microphone diaphragm, in a vertical plane, at 1.2 m above ground level and clear of obstacles, including the operator, when in use. A spherical windscreen (B and K type 02737) made of aerated light fabric is placed over the microphone for protection without its acoustical properties being affected (see Fig. 8.5).

The description "Precision Sound Level Meter" implies that the instrument fulfils the requirements of IEC 179 and BS 4197, 1967, for which the tolerance levels for A-weighting are shown in Table 8.1. This was verified by calibrating the two instruments with a B and K microphone calibration apparatus (type 4142) using the electrostatic actuator. The latter was excited by a beat frequency oscillator (B and K type 1014) calibrated in accordance with the manufacturer's instructions supplied in the handbook. The A-weighted sound level meter output was fed through the audio spectrometer, switched to level response for the range 20 to 20,000 Hz, to the level recorder which was adjusted for a dynamic range of 50 dB. The arrangement used for calibration is illustrated in Fig. 8.6.

The calibrations of the sound level meters over the frequency range 25 to 20,000 Hz were plotted by means of the level recorder. The electrostatic actuator gives only the pressure response of the instruments but, using data provided

TABLE 8.1

PERFORMANCES OF SOUND LEVEL METERS COMPARED WITH THE REQUIREMENTS LAID DOWN BY I.E.C. 179 AND B.S. 4197, 1967

FREQUENCY	REQUIREMENTS FOR A-WEIGHTING FOR PRECISION SOUND LEVEL METER			PERFORMANCES OF A-WEIGHTED SOUND LEVEL METERS USED IN PRESENT INVESTIGATIONS			
	LEVEL	TOLERANCE LIMITS		Ser. No. 363126		Ser. No. 265229	
				LEVEL	DEV'N	LEVEL	DEV'N
Hz	dBA	dBA	dBA	dBA	dBA	dBA	dBA
10	-70.4	+5	-∞	...	...	...	...
12.5	-63.4	+5	-∞	...	...	...	...
16	-56.7	+5	-∞	...	...	...	...
20	-50.5	+5	-5	...	...	...	...
25	-44.7	+5	-5	-41	+4	-40	+5
31.5	-39.4	+3	-5	-39	+0.5	-36	+3.5
40	-34.6	+3	-3	-35	-0.5	-32	+2.5
50	-30.2	+3	-3	-31	-1	-29	+1
63	-26.2	+3	-3	-25	+1	-25	+1
80	-22.5	+2	-2	-22.5	0	-21	+1.5
100	-19.1	+1	-1	-19	0	-18	+1
125	-16.1	+1	-1	-16	0	-16	0
160	-13.4	+1	-1	-13.5	0	-12.5	+1
200	-10.9	+1	-1	-11	0	-10	+1
250	- 8.6	+1	-1	- 8.5	0	- 8.5	0
315	- 6.6	+1	-1	- 6.5	0	- 6	+0.5
400	- 4.8	+1	-1	- 4.5	+0.5	- 4	+1
500	- 3.2	+1	-1	- 3.5	-0.5	- 3	0
630	- 1.9	+1	-1	- 2	0	- 2	0
800	- 0.8	+1	-1	- 1	0	- 0.5	+0.5
1 000	0	+1	-1	0	0	0	0
1 250	+ 0.6	+1	-1	+ 0.5	0	+ 0.5	0
1 600	+ 1.0	+1	-1	+ 1	0	+ 1	0
2 000	+ 1.2	+1	-1	+ 1	0	+ 1	0
2 500	+ 1.3	+1	-1	+ 1	-0.5	+ 1	-0.5
3 150	+ 1.2	+1	-1	+ 1	0	+ 1	0
4 000	+ 1.0	+1	-1	+ 1	0	+ 1	0
5 000	+ 0.5	+1.5	-1.5	+ 1	+0.5	+ 0.5	0
6 300	- 0.1	+1.5	-2	+ 0.5	-0.5	0	0
8 000	- 1.1	+1.5	-3	- 1	0	- 2	-1
10 000	- 2.5	+2	-4	- 3	-0.5	- 3	-0.5
12 500	- 4.3	+3	-6	- 5	-1.5	- 5	-0.5
16 000	- 6.6	+3	-∞	- 9	-2.5	- 8	-1.5
20 000	-11.1	+3	-∞	-12	-1	-12	-1

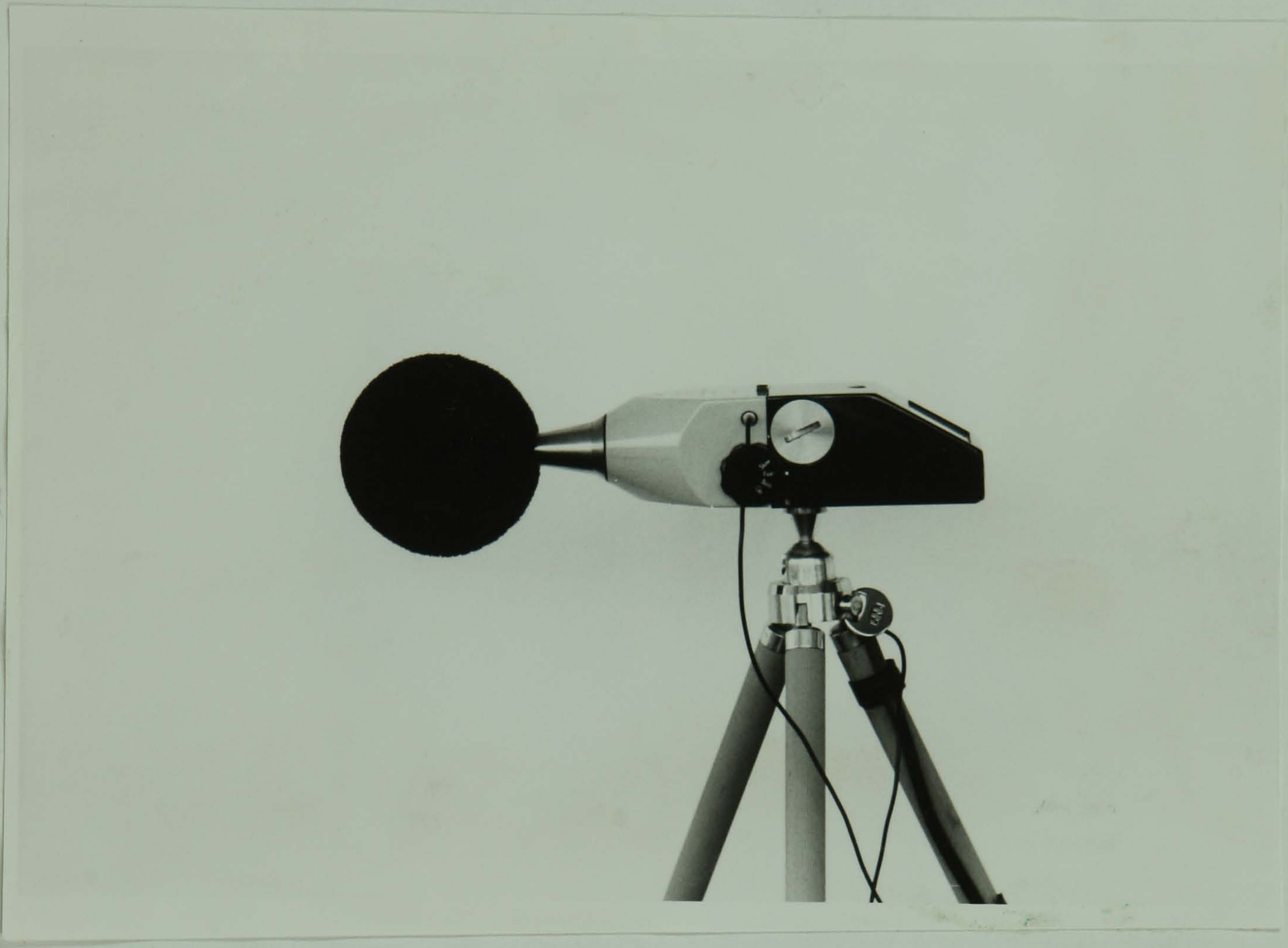


Fig. 8.5 Mounting of Sound Level Meter on tripod with windshield placed over microphone.

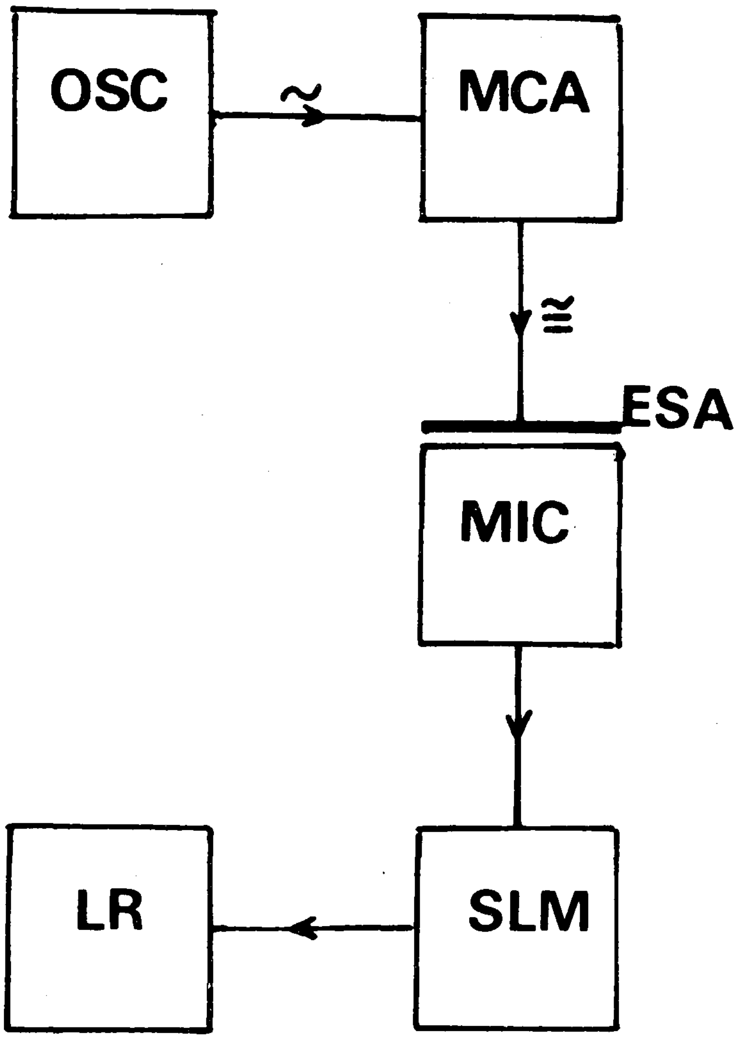


Fig. 8.6 Arrangement for calibration of Sound Level Meter using Electrostatic Actuator.

OSC = Oscillator.

MCA = Microphone Calibration Apparatus (carries Oscillator signal and provides DC bias to the electrostatic actuator).

ESA = Electrostatic Actuator.

SLM = Sound Level Meter.

LR = Level Recorder.

by the manufacturers, which corrects for the effect of the finite size of the microphone in relation to wavelength at the higher frequencies, free-field calibrations were obtained. The frequency response could be measured to ± 0.5 dB and the sound levels at different frequencies, compared with those at 1000 Hz, are given in Table 8.1. It is seen that for the frequency range, 25 to 20,000 Hz, both instruments fulfilled the requirements of IEC 179 for A-weighting.

It is to be noted that the dynamic ranges of each of the sound level meters are 48 dB, with the attenuators switched to 90 dB, and 40 dB, with the attenuators switched to 80 dB. When used in the field, the responses of frequencies below 25 Hz could not be obtained without resetting the attenuator. However, in practice, it is not feasible to change the attenuator setting during a recording and, in any case, the tolerances at the lower frequencies are large.

In practice, it is extremely unlikely that the sound level at a distance of 10 m from the roadside would exceed 90 dBA and recordings were made with the 80 dB attenuator setting to provide a dynamic range from 50 to 90 dBA. The attenuator setting was changed to 90 dB only for calibration purposes.

The overall accuracy of the Sound Level Meter in measuring a noise level in dBA was determined as follows. A loop was made of part of a tape used in recording, with A-weighting, the sound from a heavy vehicle. It was then played back through the Audio Spectrometer, switched to octave band analysis. The meter readings (in dBA) of this instrument were noted for the 9 octave bands centred at the frequencies ranging from 31.5 to 8000 Hz (Table 8.3). The tolerance limits determined for each frequency band (see Table 8.1) were added to and subtracted from, respectively to these readings to provide both the upper and lower limits in dBA. These were converted to intensities and summed to provide both the upper and lower limits of overall intensities for the frequency range. They were then reconverted to dBA to yield the effective tolerance limits of the instrument, as shown in Table 8.2.

It is seen that the overall tolerance limits for the A-weighted sound level meters for the range 31.5 to 8000 Hz were ± ~~0.9~~ 1 dBA.

8.1.3 Portable Tape Recorders (Uher 4000 Report L (Mono) and 4200 Report L (Stereo)).

With the stereo tape recorder switched to channel 1 both instruments were nominally identical in performance. They were powered in the field by accumulators with stabilised outputs and in the laboratory by stabilised D.C. power supplies. Their dynamic range was 50 dB. At all times they were operated at a speed of 190 mm s^{-1} (7.5 in. s^{-1}).

The frequency responses of the tape recorders were measured using the B.F.O. audio spectrometer, switched to a flat ~~that~~ response over the range 20 to 20,000 Hz, and the level recorder. The measured responses are given in Table 8.3. It is seen that, for both instruments, the responses are level to within ± 0.5 dB for the range from 100 to 10,000 Hz.

TABLE 8.2

ASSESSMENT OF TOLERANCE LIMITS OF THE PRECISION SOUND LEVEL METER

OCTAVE BAND CENTRE FREQUENCY	MEASURED NOISE LEVELS	TOLERANCE LIMITS		LIMITS OF MEASURED NOISE LEVELS		LIMITS OF EQUIV. INTENSITIES	
		UPPER	LOWER	UPPER	LOWER	UPPER	LOWER
Hz	dBA	dBA	dBA	dBA	dBA	$Wm^{-2} x 10^{8}$	$Wm^{-2} x 10^{8}$
31.5	68	+3	-3	71	65	0.10	0.03
63	78	+3	-3	81	75	1.30	0.32
125	86	+1	-1	87	85	5.00	3.16
250	84	+1	-1	85	83	3.16	2.00
500	81	+1	-1	82	80	1.59	1.00
1000	81	+1	-1	82	80	1.59	1.00
2000	76	+1	-1	77	75	0.50	0.32
4000	63	+1	-1	64	62	0.03	0.02
8000	51	+1.5	-3	52.5	48	0.00	0.00
				TOTALS		13.27	7.85
				EQUIV. LEVELS IN dBA		91·2 ~~90.8~~	89.0
				MEAN LEVEL IN dBA		90 ± 1 ~~89.9 ± 0.9~~	

TABLE 8.3

FREQUENCY RESPONSES OF TAPE RECORDERS

FREQUENCY Hz	25	31.5	40	50	63	80	100	125
LEVEL - MONO dB	-19	-14	-10	-6	-4	-2	-0.5	0
- STEREO (CHANNEL 1) dB	-8	-6	-5	-2	-2	0	0	0

FREQUENCY Hz	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500
LEVEL - MONO dB	0	+0.5	+0.5	+0.5	0	0	0	0	0	0	0	0	-0.5
- STEREO (CHANNEL 1) dB	0	0	0	0	0	0	0	0	0	0	-0.5	-0.5	-0.5

FREQUENCY Hz	3150	4000	5000	6300	8000	10,000	12,500	16,000	20,000
LEVEL - MONO dB	-0.5	-0.5	0	0	0	-0.5	-2	-4	-6
- STEREO (CHANNEL 1) dB	-0.5	-0.5	-0.5	-0.5	0	0	0	-2	-6

8.1.4. Audio spectrometer (B and K type 2112)

This instrument can be used as an amplifier to give a flat response over the range from 20 to 20,000 dB and also to provide A, B, and C weightings in accordance with IEC 179. It possesses octave and third octave band filters over this frequency range. The centre frequencies for the octave bands are 31.5, 63 , 125, 250, 500, 1000, 2000, 4000, 8000 and 16000 Hz.

8.1.5. Level Recorder (B and K Type 2305)

The level recorder was used both for providing a visual record of noise level variations with time and also as an adjunct to the statistical distribution analyser (see Section 8.1.6).

The recorder was fitted with a potentiometer designed to provide a range of 50 dB to correspond with a maximum dynamic range of 48 dB of the sound level meter. It was found that, for chart recording, optimum values of writing and paper speeds were 100 and 3 mm s^{-1}, respectively.

8.1.6. Statistical Distribution Analyser (B and K Type 4420)

This instrument, illustrated schematically in Fig.8.7 is designed to operate with the B and K Level Recorder Type 2305 (see section 8.1.5). A conducting slider attached to the writing arm of the level recorder moves over a series of contacts, each of which is connected to a counter. Short pulses, generated at regular intervals, pass through the slider and are registered by the counter corresponding to the

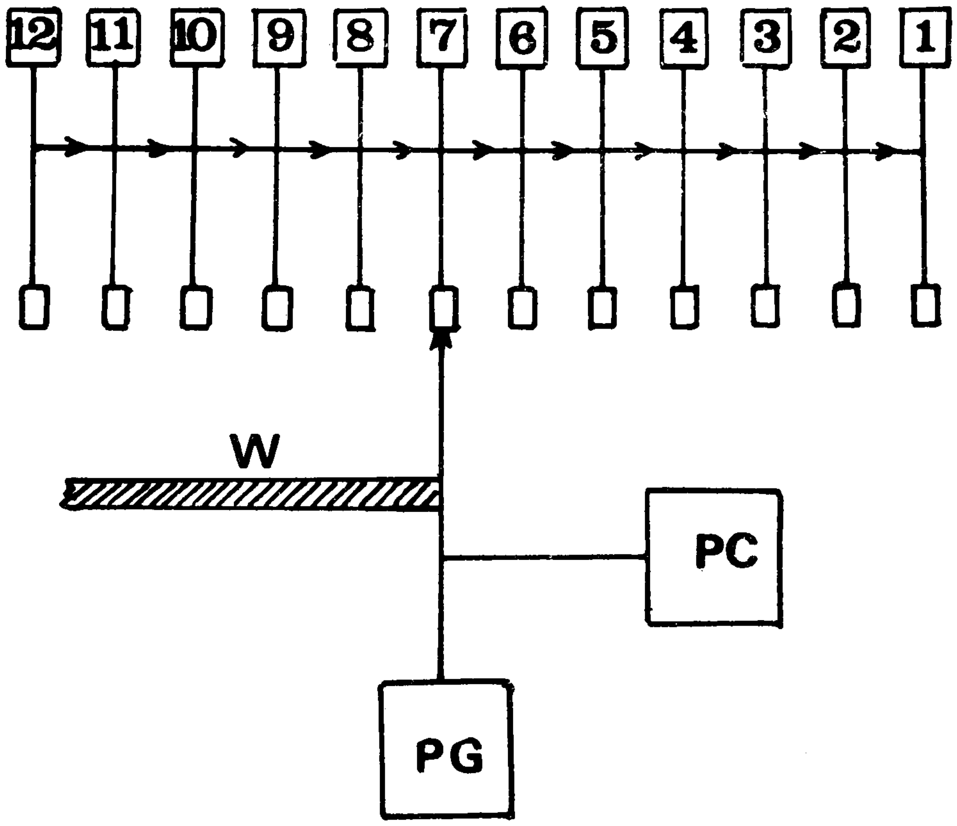


Fig. 8.7 Fundamental principles of the B and K Statistical Distribution Analyser (Type 4420).

W = writing arm of Level Recorder.

PC = pulse counter.

PG = pulse generator.

Numerals indicate channel counters.

point of contact. An additional counter registers the total number of pulses generated. Diodes connecting each contact with its neighbour are switched in for cumulative counting.

Here, with the level recorder adjusted to a 50 dB range, contacts are made for levels from 50 to 95 dB at 5 dB intervals, i.e. only 10 of the 12 counters being in operation. The use of the maximum pulse repetition frequency of 10 s^{-1} enables one to obtain the highest count in the shortest possible time for high traffic densities. On the other hand it still provides sufficient time (999.9s) for statistical requirements to be satisfied at low traffic densities. The head of the sliding arm has the same effective area as each of the contacts. Thus connection is maintained to one or two of the contacts during the whole period of recording. When simultaneous connection to two contacts takes place, the pulse is registered only by the counter corresponding to the higher level, if the instrument is used to provide a simple statistical distribution count. The analyser may be stopped automatically after a required number of counts (e.g. 9999). For ease of calculation, when plotting results on probability paper, this number or a simple fraction of it (e.g. 3333, 999, etc.) is selected, depending on the time of duration of recording.

When a simple distribution count is required the pulses between neighbouring channels are blocked and the counters indicate the number of 0.1 s intervals during the time of recording for which the traffic noise level falls within a given 5 dB range, e.g. 60-65 dB. A plot of the number of counts against level takes the form illustrated in Fig. 8.8. The continuous curve superposed on the histogram indicates a Gaussian distribution. This type of distribution was found to occur with the recorded variations of traffic noise levels with time.

In the work forming the main basis of this thesis cumulative counts were required in order to determine values of L_{10}, L_{50} and L_{90} and the pulses between neighbouring channels were unblocked. In this case the counters indicated the number of 0.1 s periods during which given levels were exceeded. A plot of counter indications against level, corresponding to the histogram given in Fig. 8.8 is shown in Fig. 8.9. The continuous curve shown here corresponds to a cumulative Gaussian distribution.

To determine L_{10}, L_{50} and L_{90}, i.e. the levels exceeded for 10, 50 and 90 per cent, respectively, of a given period, the counts are plotted on probability graph paper (see Fig.8.10). On this type of paper the projections of the abscissa, i.e. number of counts on the curve of Fig.8.9, provide the graduations of the x-axis, with the spacings between them greatest at the extremities. The y axis of a probability curve is linear. L_{10}, L_{50} and L_{90} are read off as shown. The closer the plot to a straight line the closer the noise level variations follow a Gaussian distribution.

8.1.6. Gradiometer

The instrument used for measuring gradients is illustrated in Fig. 8.11. It consists essentially of two bars of Dexion angle iron hinged together. A spirit level is fixed to one of

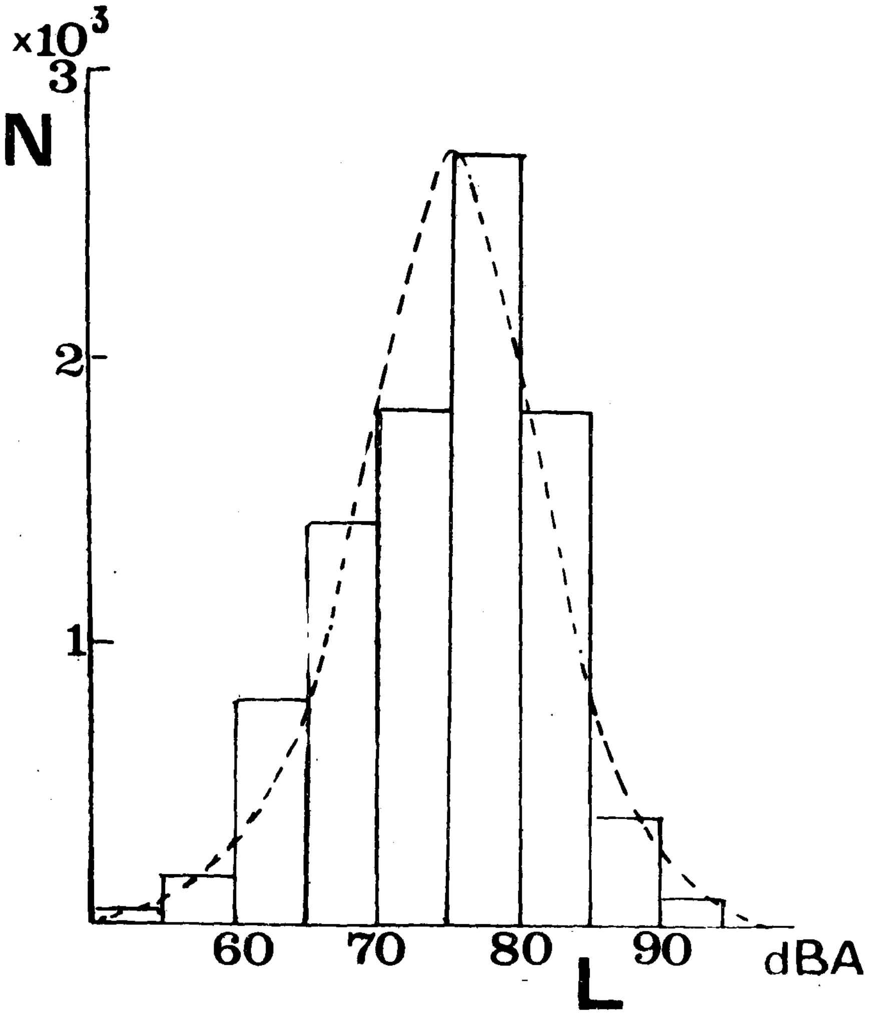


Fig. 8.8 Histograms of probability distribution (number N of counts against sound level L in dBA) for a period of 9999 intervals of 0.1 s, with a range of 50 dB.

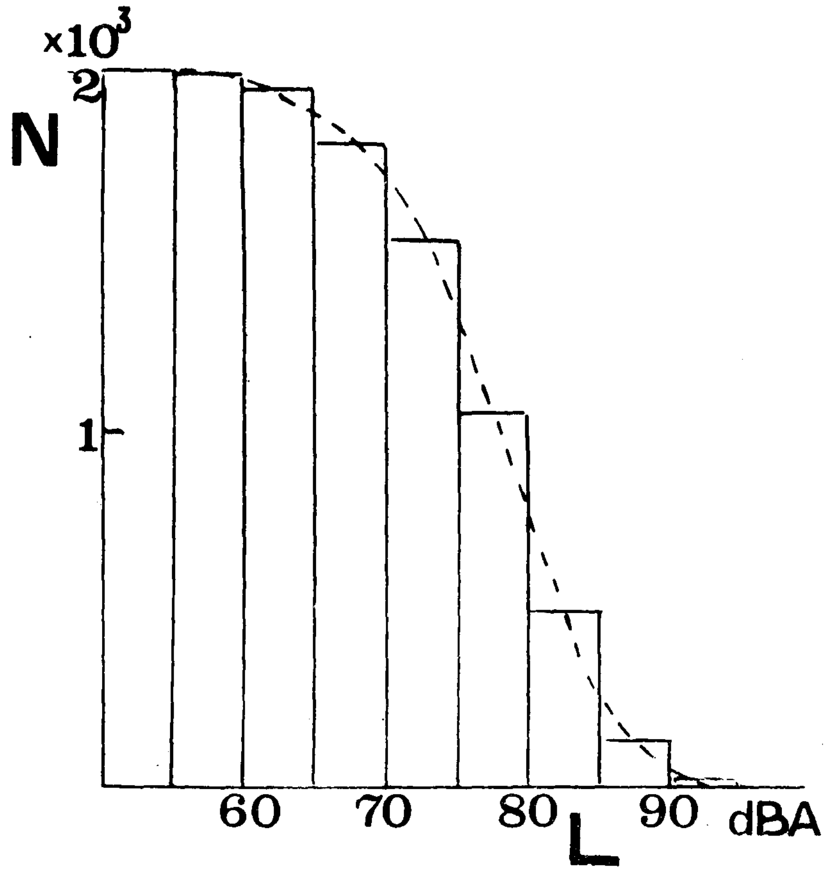


Fig. 8.9 Cumulative plot corresponding to the probability distribution shown in Fig. 8.8.

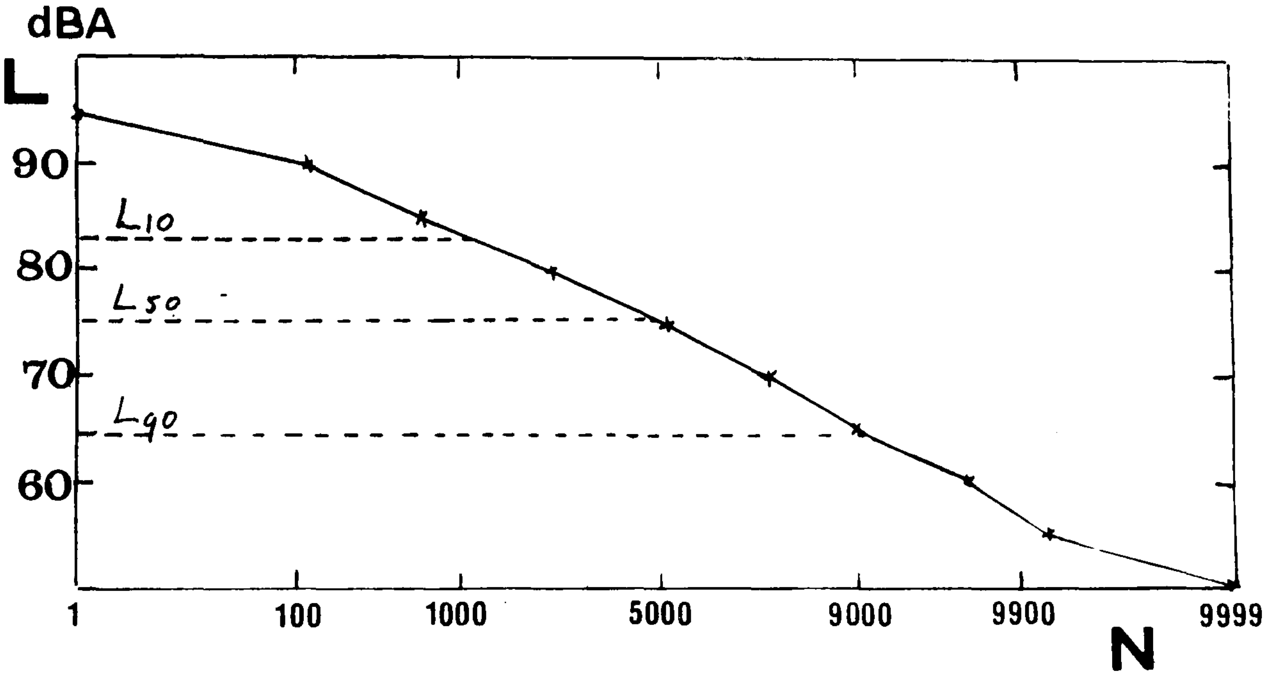


Fig. 8.10 Plot of Fig. 8.9 on probability paper.

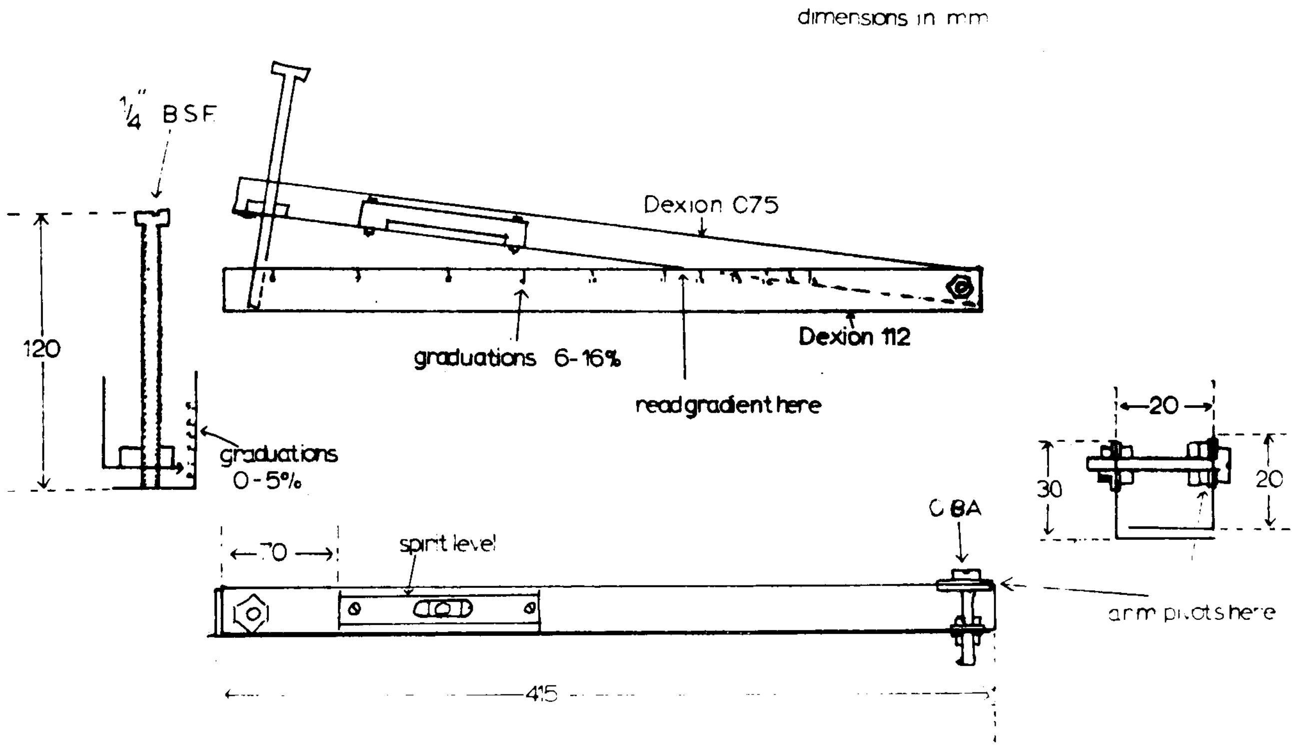


Fig. 8.11 Design of Gradiometer.

the bars. The method of measuring gradient in per cent is self-evident with reference to the diagram. The device was calibrated using an inclined surface and a ruler.

8.1.7 Tally Counters

These are commercially available 5-figure counters operated by a lever. They are mounted in banks of three to enable the operator to count three different classes of passing vehicles during the time of observation. The bank of three counters can be held in one hand and the levers moved by the thumb.

8.2 RECORDING OF ROAD TRAFFIC NOISE.

Noise level recordings at each of the chosen sites were made with a sound level meter, (section 8.1.2.) generally switched to A-weighting, mounted on a tripod (see Fig. 8.5) with the microphone 1.2 m above ground level. The microphone diaphragm lay in a vertical place and faced the road. The microphone was fitted with a windshield which minimised the effects of wind without altering the acoustic characteristics of the instrument. The sound level meter was connected by means of a cable 10 m long to a portable tape recorder (section 8.1.5). A remote control was used for pause operation of the tape recorder to eliminate extraneous noises (e.g. from aircraft and intrusive passers-by) without the operator having to go near the equipment.

Initially a 94 dB re 20 x 10^{-6} N m^{-2} calibration signal at 1000 Hz was applied for 1 minute to the sound level meter using the calibrator, as described in section 8.1.2. The recording was then made for the appropriate time, e.g. 999.9 s, but less for heavier traffic densities. A check calibration signal was applied at the end of the recording. Banks of tally counters held in each hand were used to record the numbers of different classes of vehicle, i.e. heavy and light and, in later measurements, three axle heavy vehicles proceeding in both directions. The category of light vehicles included private cars, taxis and vans of less than 30 cwt. capacity. Heavy vehicles included commercial vehicles of greater than 30 cwt. capacity, public service vehicles and motor cycles. Initially recordings were made simultaneously with the sound level meter both at kerbside and at 10 m back from the kerb, but subsequently only at 10 m from kerbside. The observations were made on the side of the road where traffic proceeded uphill.

Gradients were measured with the gradiometer (section 8.1.6) at the centre of the road at intervals of 1 m over a distance of 10 m about the point of observation. The mean value recorded determined the gradient. Where the gradient was found not to be uniform, i.e. the fractional standard deviation from the mean value exceeded 0.1 for small gradients and 0.05 for large gradients, the site was abandoned. The road width was determined by means of a tape measure.

The following criteria were adopted for the choice of site:

(1) Uniform gradient in the vicinity.

(2) Absence of tall buildings and of buildings close to the roadside.

(3) For measurements at 10 m from the kerbside, a wide angle subtended by the road and absence of obstructions, e.g. nearby walls, pillar-boxes, etc.

(4) A stoned asphalt road surface.

(5) Absence of intersections, pedestrian crossings, traffic lights, road islands, parked cars and any other impediments to freely flowing traffic.

(6) Absence of extraneous noise sources, e.g. railways and construction sites.

(7) A single carriageway road subjected to a 30 m.p.h. speed limit and wide enough to permit freely flowing traffic but generally not wide enough to encourage excessive overtaking.

Measurements were made only under the following conditions:

(1) Absence of precipitation and fog.

(2) Light and variable winds.

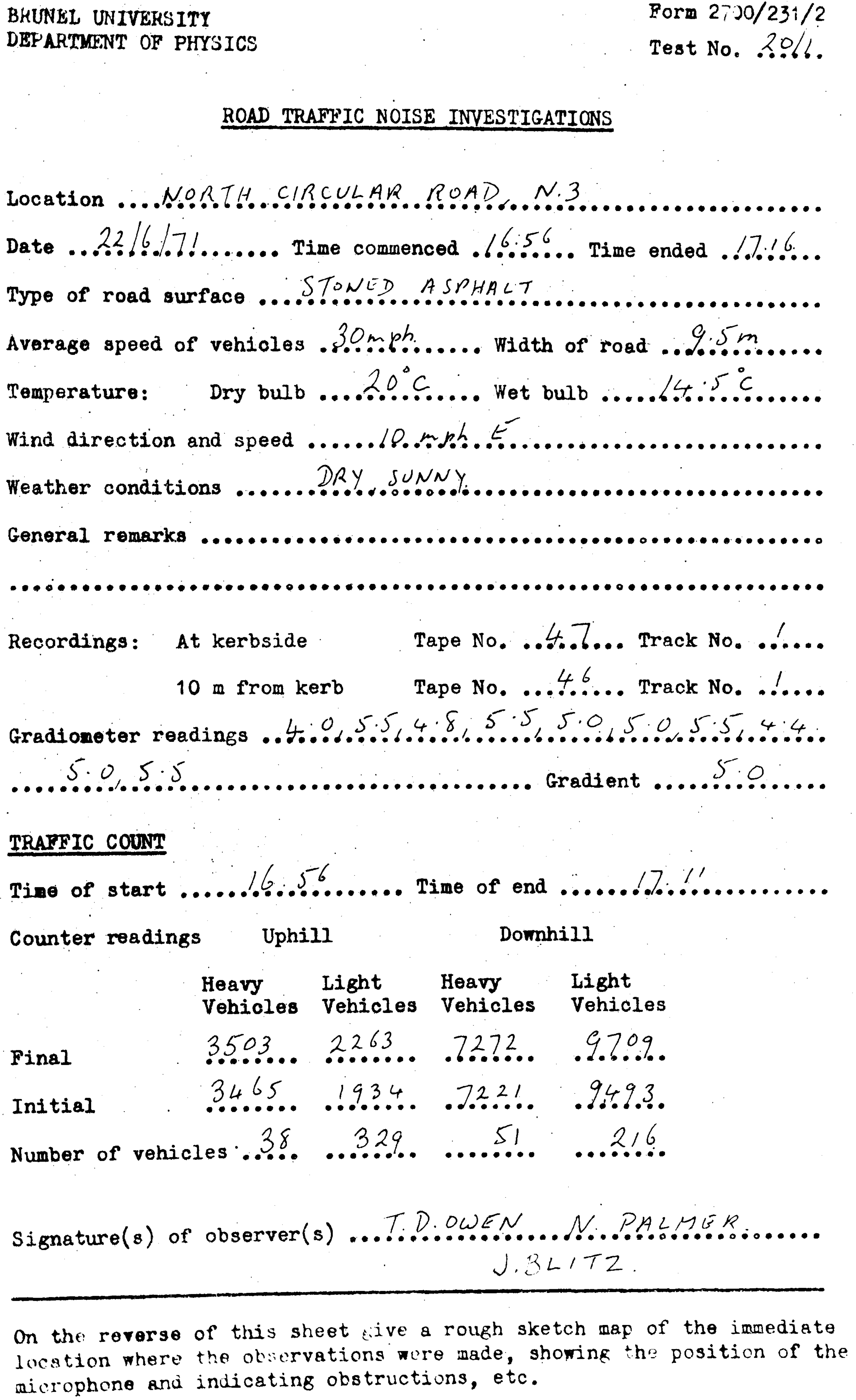
(3) Dry road surfaces.

(4) Temperature and humidity conditions suitable for trouble-free operation of the equipment.

Sample checks of traffic speed were made from time to time. Speed was determined by measuring with a stop-watch the time taken for individual vehicles to pass two landmarks a measured distance apart. The positions of barriers and reflecting surfaces were noted for each site in case allowances might have to be made for these when comparing results obtained from other sites. Details of measurements were entered on the form shown in Fig. 8.12. Further information, e.g. a sketch of the surroundings including positions of obstacles and reflecting surfaces was entered at the foot of the reverse side of the form.

8.3 ANALYSES

The analyses of the recordings were made in the laboratory. The tape recordings were played back on the same instrument on which the recording was made and at the same speed (190 mm s^{-1}, i.e. 7.5 in. s^{-1}). The instrument, powered by means of a mains converter, was connected through the level recorder to the statistical distribution analyser switched to cumulative counting. If the recordings were made on C-weighting the audio spectrometer was switched into the circuit to provide the required weighting, e.g. A-weighting or octave analyser. The setting of the level recorder was calibrated with the recorded 94 dB signal. The readings of the statistical analyser were entered on the reverse side of the form (Fig.8.12(a)). These were plotted on probability paper (Fig. 8.10). The final results were entered on another form (Fig. 8.13).



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Form 2700/231/2
Test No. 2011.

ROAD TRAFFIC NOISE INVESTIGATIONS

Location NORTH CIRCULAR ROAD, N.3

Date 22/6/71 Time commenced 16.56 Time ended 17.16

Type of road surface STONED ASPHALT

Average speed of vehicles 30 mph Width of road 9.5 m

Temperature: Dry bulb 20°C Wet bulb 14.5°C

Wind direction and speed 10 mph E

Weather conditions DRY, SUNNY

General remarks

Recordings: At kerbside Tape No. 47 Track No. 1

10 m from kerb Tape No. 46 Track No. 1

Gradiometer readings 4.0, 5.5, 4.8, 5.5, 5.0, 5.0, 5.5, 4.4, 5.0, 5.5 Gradient 5.0

TRAFFIC COUNT

Time of start 16.56 Time of end 17.11

Counter readings	Uphill		Downhill	
	Heavy Vehicles	Light Vehicles	Heavy Vehicles	Light Vehicles
Final	3503	2263	7272	9709
Initial	3465	1934	7221	9493
Number of vehicles	38	329	51	216

Signature(s) of observer(s) T. D. OWEN N. PALMER
J. BLITZ.

On the reverse of this sheet give a rough sketch map of the immediate location where the observations were made, showing the position of the microphone and indicating obstructions, etc.

Fig. 8.12. Specimen form completed by observer for a traffic noise recording.

STATISTICAL ANALYSER READINGS

	At kerbside	10 m from kerb
1.	9999	9999
2.	9999	9999
3.	9999	9999
4.	9978	9999
5.	9451	9999
6.	8175	9807
7.	5666	8813
8.	2580	5634
9.	598	1787
10.	121	232
11.	7	19
12.	0	0

N.B Readings 10dB lower than for kerbside

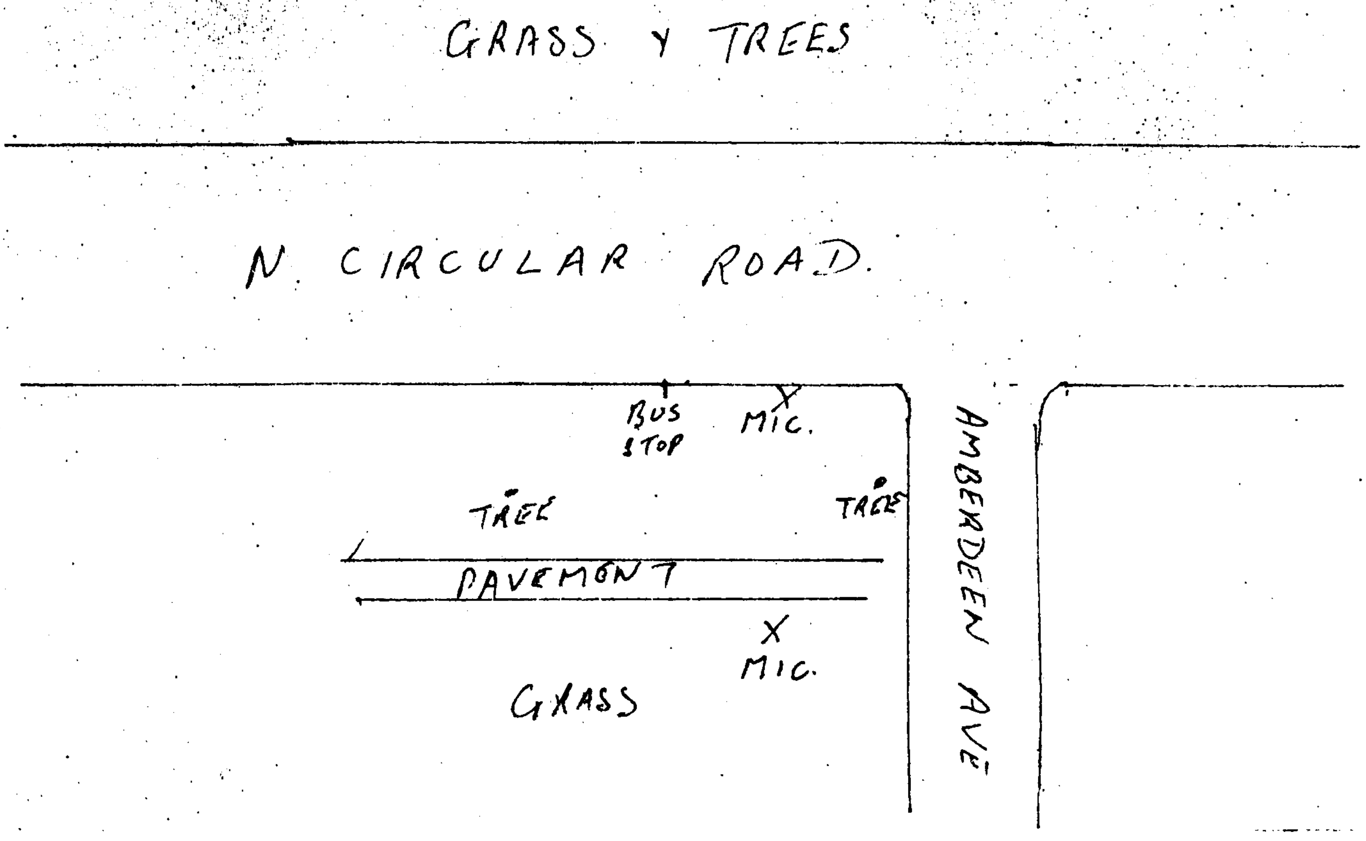

Fig. 8.12 (a). Reverse side of form shown in Fig. 8.12.

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DEPARTMENT OF PHYSICS

Form 2700/231/1

Test No. 20/1

ROAD TRAFFIC NOISE INVESTIGATIONS

Location NORTH CIRCULAR ROAD N 3

Date 22/6/71 Time 16.56

Temperature 20°C Relative humidity 54%

Gradient 5% Width of road 9.5 m

Average speed of vehicles 30mph Wind direction and speed 10mph E

Type of road surface STONED ASPHALT

Weather conditions DRY, SUNNY

TRAFFIC DENSITY

(Vehicles per hour)	Directions		Total
	Uphill	Downhill	
Heavy vehicles	152	204	356
Light vehicles	1316	864	2180
Total	1468	1068	2536
% Heavy	10·5	19	14

NOISE LEVELS

	At kerbside	10 m from kerb
L_{10} dBA	83·3	76·5
L_{50} dBA	76·2	70·7
L_{90} dBA	67·2	59·5

Fig. 8.13. Form summarising information given in Fig. 8.12.

CHAPTER 9.

PRELIMINARY INVESTIGATIONS OF THE EFFECTS OF GRADIENTS ON ROAD TRAFFIC NOISE.

9.1 GENERAL CONSIDERATIONS.

46 sites, listed in Appendix 1 were selected for the investigation of the effects of gradients on road traffic noise. These sites were located on roads having gradients ranging from 0.3 to 11.2 per cent. By selecting as large a number as possible it was hoped to even out variations in characteristics such as nature of the surroundings and width of road. The sites were chosen in accordance with the requirements laid down in Section 8.2. On selection of each suitable site, a few sound level recordings were made by way of preliminary investigation and the values of L_{10}, L_{50} and L_{90}, together with rates of flow of light and heavy traffic determined. These are listed in Table A1.1 in Appendix 1.

Following the procedure of Stephenson and Vulkan (22, 34) recordings were made at kerbside. Measurements were also taken at positions 10 m back from the kerb simultaneously with the kerbside measurements, except in those sites where conditions did not permit this. At the 10 m position the noise should be more characteristic of traffic as a whole rather than individual vehicles, as at the kerbside positions. Furthermore, the distance of 10 m from roadside, equivalent to about 15 m from the centre line of the road, should be large enough for ~~dense~~ traffic to be considered to flow along this centre line and thus for L_{10}, L_{50} and L_{90} to vary with distance in a relatively simple manner, as discussed in Chapters 6 and 7.

The observed variations of L_{10}, L_{50} and L_{90} with traffic densities and gradients are considered in the following sections. Also discussed are possible effects on noise levels of site characteristics.

9.2 VARIATIONS OF L_{10}

To permit easy comparison with the work of Stephenson and Vulkan (34) it was originally intended to use the parameter H/Q, i.e. ratio of the rate of flow H of heavy vehicles to the total rate of flow Q, and to plot L_{10} against Q for different values of H/Q and given ranges of gradient. This was not found to be practicable in view of the comparatively small number of observations taken and it was considered to be more suitable to relate L_{10} to a single parameter. In Section 7.2 it was shown theoretically that, for a sufficiently high rate of flow of heavy vehicles, e.g. more than 50 hr^{-1} and 4 per cent of the total rate of flow for a speed of 45 km hr^{-1}, L_{10} should depend only on the rate of flow H of the heavy vehicles.

Figs. A1.1(a) to (e) in Appendix 1 show relationships between L_{10} and H for both kerbside and 10 m from the kerb positions for the ranges of gradient 0 to 2, 2 to 4, 4 to 6, 6 to 8 and over 8 per cent. The experimental variations of L_{10} with H were found to be very consistent with the theoretical predictions (see Fig. 7.1). The kerbside and 10 m curves are approximately equispaced along these lengths, being separated by a mean amount of ΔL_{10} equal to 7 dBA. This is consistent with the separation of the theoretically predicted curves for L_{10} when $d = 15$ m and $d = 6$ m, as shown in Fig. 7.1.

Table 9.1 displays the mean values of L_{10} for different gradients at both kerbside and 10 m positions as obtained by

TABLE 9.1

MEAN VALUES OF L_{10} FOR DIFFERENT GRADIENTS AS OBTAINED FROM FIGS A1 (a) to (e).

H \ GRADIENT	VALUES OF L_{10}				
	0 - 2%	2 - 4%	4 - 6%	6 - 8%	> 8%
hr^{-1}	dBA	dBA	dBA	dBA	dBA
100 (K)	76.5	79	77	79.5	76.5
(10 m)	70.5	72.5	70	72	70
(ΔL_{10})	6	6.5	7	7.5	6.5
200 (K)	79.5	80	81.5	82	81
(10 m)	73	73	73.5	74.5	73.5
(ΔL_{10})	6.5	7	8	7.5	7.5
300 (K)	81	81	83	83	83
(10 m)	74	74	76	75	76
(ΔL_{10})	7	7	7	8	7
325 (10 m) (predicted)	74.5 ± 2	75.5 ± 3	74.5 ± 2	75.5 ± 2	76.5 ± 2.5

(K) denotes kerbside position.

(10 m) denotes 10 m from kerb position.

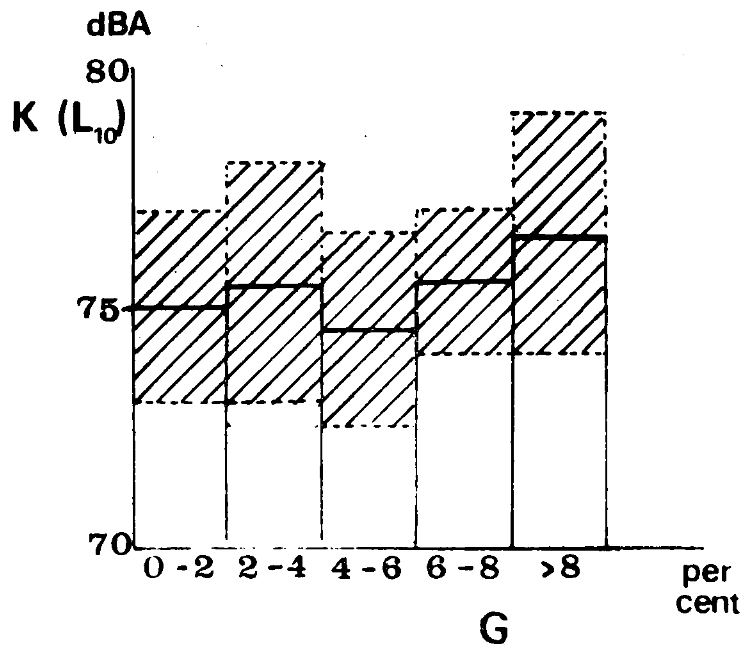

FIG. 9.1 HISTOGRAM OF VARIATION OF K (PREDICTED VALUE OF L_{10} FOR H = 325 hr^{-1}) WITH RANGE OF GRADIENT G SHOWING STANDARD DEVIATIONS (SHADED).

inspection of these curves. No variation of L_{10} with gradient is apparent in either case.

Taking recourse to the theory developed in Chapter 7 it is possible to consider all values of L_{10} determined in the 10 m position for which the rate of flow H of heavy vehicles is greater than 50 hr^{-1}, and correct them to a given value of H assuming equation 7.9, which may be written more simply as follows:

$$L_{10} = K + H/500 - \log_{10}^{-1}(1 - H/270) \qquad 9.1$$

where K is a constant. This equation is valid for an average speed of 45 km hr^{-1}, which is consistent with observations of speeds of heavy vehicles. A deviation of 5 km hr^{-1} in either direction results in an error in L_{10} of only ± 0.5 dBA.

We see from equation 9.1 that $L_{10} = K$ when $H = 325$ hr^{-1}. Each value of L_{10} for which H was greater than 50 hr^{-1} was substituted into equation 9.1 and the value of K obtained. Mean values of K for the 10 m position, together with the standard deviations for each range of gradients are given in the bottom line of Table 9.1. No clear variation of L_{10} with gradient is apparent but there is a suggestion of a slight increase for higher gradients.

The possibility of the effects on L_{10} of the predominance of either uphill or downhill traffic has been carefully considered but it was found that they are negligible. This phenomenon is discussed in Section 10.1.

9.3 VARIATIONS OF L_{50}.

For reasons stated at the beginning of the previous section it was found to be impracticable to relate L_{50} with total rate of flow Q and different ratios H/Q, where H is the rate of flow of heavy vehicles. However, it was seen that L_{50} correlates very well with the parameter $R = Q + H^2/50$, derived in Appendix 3, for both kerbside and 10 m from kerb positions as shown in Fig. A1.2 for the gradients between 2 and 4 per cent. Again, the kerbside and 10 m curves are approximately equispaced from one another along their lengths, the mean distance $\triangle L_{50}$ of separation being 6 dBA.

Table 9.2 shows the mean values of L_{50} for different gradients at both kerbside and 10 m positions, as obtained by inspection. As with L_{10}, no variation of L_{50} with gradient is apparent for either kerbside or 10 m positions.

By correcting each determined value of L_{50} for Q greater than 750 hr^{-1} and H less than 250 hr^{-1} with the aid of equation A3.9, mean values together with standard deviations can be obtained for the 10 m position (see Table 9.2). Fig. 9.2 shows a histogram plot of the corrected values of L_{50} against gradient. No definite trend is apparent. There is an indication of a peak within the range 2 to 4 per cent, as with L_{10}, but this ~~is almost certainly~~ may well be due to factors other than the effects of gradient. However, as before, there is a slight indication of an increase in level with gradient for steeper roads.

9.4. VARIATIONS OF L_{90}.

For reasons discussed when considering the variations of L_{10} and L_{50} with total rate of flow Q and rate of flow of heavy

TABLE 9.2

MEAN VALUES OF L_{50} FOR DIFFERENT GRADIENTS AS OBTAINED FROM PLOTTED DATA.

	VALUES OF L_{50}				
GRADIENT / R	0 - 2%	2 - 4%	4 - 6%	6 - 8%	> 8%
hr^{-1}	dBA	dBA	dBA	dBA	dBA
1000 (K)	67	71	67	69	70
(10 m)	62	64.5	62	63	63
(ΔL_{50})	5	6.5	5	6	7
2000 (K)	72	74	72.5	71	73.5
(10 m)	66	68	67	65.5	67
(ΔL_{50})	6	6	5.5	5.5	6.5
3000 (K)	75.5	75	74	73.5	74
(10 m)	69	69	68	67.5	69
(ΔL_{50})	6.5	6	6	6	5
1000 (10 m) (predicted)	64 ± 3	65 ± 2	62 ± 3	63 ± 1.5	64 ± 2

(K) denotes kerbside position.

(10 m) denotes 10 m from kerb position.

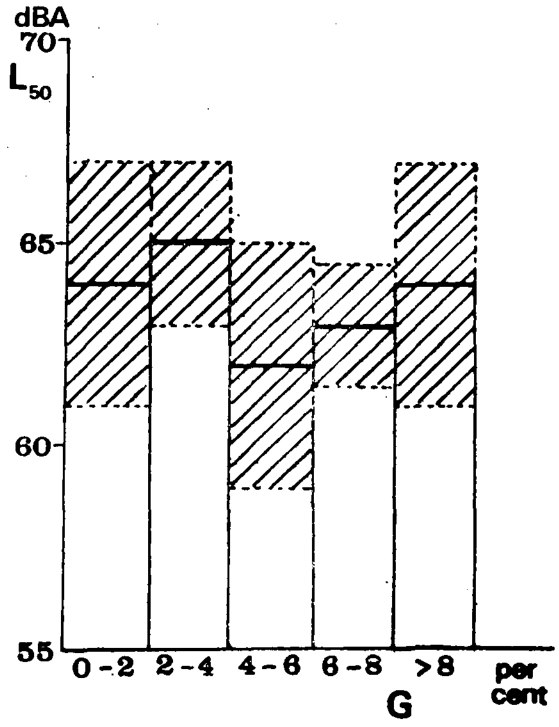

FIG. 9.2 HISTOGRAM OF VARIATION OF L_{50} (R = 1000 hr^{-1}) WITH RANGE OF GRADIENT G, SHOWING STANDARD DEVIATIONS (SHADED).

vehicles H, it was found desirable to relate L_{90} ~~with~~ to a single parameter. In Section A3.2 it is shown that the quantity R' = Q + H^2/100 should serve as a suitable parameter and good correlation was obtained by plotting L_{90} against R' for both kerbside and 10 m positions with different ranges of gradient. (See Fig. A1.3 relating to gradients above 8 per cent.) The vertical spacing between the lines averages 4 dBA but it is no longer constant, except for higher values of R'. The smaller differences for low values of R' may indicate that noise from sources other than road traffic contribute to L_{90}.

Table 9.3 gives values of L_{90} for different values of R', as far as possible, as obtained by inspection of the plotted curves. There appears to be some tendency for an increase in L_{90} to take place with gradient for higher values of R' but the amount of data upon which these findings are based is insufficient for any high degree of confidence to be assumed.

9.5 EFFECTS OF THE ENVIRONMENT ON ROAD TRAFFIC NOISE

In the previous sections it was shown that the differences ΔL_{10}, ΔL_{50} and, to a lesser extent, ΔL_{90} between L_{10}, L_{50} and L_{90} respectively for kerbside and 10 m positions have what appears to be fairly constant mean values of 7, 6 and 4 dBA with variations of the flow parameter. However, if we consider a given value of either H, R or R', there is generally a wide distribution of the corresponding noise levels.

An inspection of Table A1.1 shows, in many cases, wide deviations from average values of ΔL_{10}, ΔL_{50} and ΔL_{90}.

TABLE 9.3

MEAN VALUES OF L_{90} FOR DIFFERENT GRADIENTS AS OBTAINED FROM PLOTTED DATA.

	VALUES OF L_{90}				
GRADIENT R'	0 - 2%	2 - 4%	4 - 6%	6 - 8%	>8%
hr^{-1}	dBA	dBA	dBA	dBA	dBA
1000 (K)	57	63	56	60.5	62
(10 m)	55	59	56	58	56
(ΔL_{90})	2	4	0	2.5	6
2000 (K)	65.5	64	66	67	67
(10 m)	62	60	62	63	62
(ΔL_{90})	3.5	4	4	4	5
3000 (K)	-	65	68	69.5	70
(10 m)	-	60.5	64	64.5	65
(ΔL_{90})	-	4.5	4	5	5

(K) denotes kerbside position.

(10 m) denotes 10 m from kerb position.

Generally, for sites such as Upper Ham Road (38), Muswell Hill (14), East Heath Road (10) and (11) and Hanger Lane (15), having open aspects, the differences between kerbside and 10 m levels are higher than the averages and for locations such as Watford Road (1), Haverstock Hill (13) and Blackheath Hill (25) and (27), which are more closed in due to the presence of buildings close to the roadside, the differences are lower than the averages. However, Shooters Hill Road (26), North Circular Road (20) and Gore Hill (3) which have open aspects do not appear to conform to this trend. Because of the comparatively small number of simultaneous kerbside and 10 m from the kerb recordings which have been made, one cannot readily come to a conclusion as to the reason for this anomaly and further investigations are necessary.

It will be noted that road widths are given for each of the sites in Table A1.1. One might expect higher values of sound levels, especially at kerbside, for narrower than for wider roads. However, except perhaps for East Heath Road (10) having a width of only 6.5 m, which in any case has an open aspect, this is not apparent from the results. In most cases the variations of road width are relatively small and should make little difference to recorded noise levels, even at the kerbside.

An important conclusion from observing relative values of $L_{10} - L_{50}$ and $L_{50} - L_{90}$ is that, in most cases, they ~~latter does not~~ are approximately equal ~~exceed the former~~. This indicates, if one assumes its variations with time follow a normal distribution, that road traffic is generally responsible for the background noise in the vicinity of main urban roads.

CHAPTER 10.

MAIN INVESTIGATION OF THE EFFECT OF GRADIENTS ON ROAD TRAFFIC NOISE.

The preliminary investigation described in Chapter 9 took place during the period April to September 1971. Two operators worked together at each of the 46 sites and obtained, as far as possible, simultaneous recordings of road traffic noise at kerbside and 10 m from the kerb positions. Comparatively few readings were obtained at a relatively large number of sites. The intention of the main investigation was to extend the number of readings at each of the sites under as many different conditions of traffic flow~~ing~~ as possible, to obtain a wide spread of results.

The sound level recordings had to be restricted to the Spring and Summer months to avoid adverse weather conditions and to take advantage of dry mild evenings and early mornings, when the effects of low traffic densities could be examined. It was therefore decided to make full use of the available resources, i.e. two sets of recording equipment and two operators to carry out the measurements, simultaneously at different sites and to postpone the analyses until the weather was less favourable for recordings. This meant discontinuing kerbside observations and recording from the 10 m from the kerb position only. During the period April to September 1972 it was thus possible to obtain 777 recordings at 18 sites, 17 of which were used the previous year and an additional one at Balham Hill (47).

It had been hoped to obtain many more recordings at a larger number of sites, but this was not possible for the following reasons:

1. Adverse weather conditions, caused mainly by high winds and also by low temperatures and high humidities during early mornings and late evenings, which prevented the proper functioning of the capacitor microphones.

2. A series of misfortunes resulting in some of the equipment being out of action at times.

Some of the originally chosen sites were unsuitable for recording in the 10 m position and one of them, Rochester Way (29) was rendered unusable as a result of major road reconstruction.

Details of the characteristics of each of the sites where recordings were made are given in Tables A2.1 (a) to (r). The tables also include the determined values of L_{10}, L_{50} and L_{90} together with the measured values of the total rate of flow Q and the rate of flow H of heavy vehicles. The results obtained from the preliminary measurements are also given and identified by asterisks.

As before, no correlation could be found between the sound levels and the predominance of either uphill or downhill rates of flow. This may be illustrated by reference to Table 10.1 which contains a short selection of measurements obtained at North Circular Road (20) where there is a gradient of 5 per cent and where traffic densities are high for much of the day. A probable explanation is that traffic travelling uphill reduces its speed and hence the tyre noise. Changing into a lower gear causes an increase in noise level and tends to counteract this effect. However, heavy vehicles change gear on gradients

TABLE 10.1.

SELECTION OF VALUES OF SOUND LEVELS OBTAINED AT NORTH CIRCULAR ROAD (20), 5% GRADIENT, SHOWING SEPARATE UPHILL AND DOWNHILL FLOWS.

Q = TOTAL RATE OF FLOW.
H = RATE OF FLOW OF HEAVY VEHICLES.

TEST NO.	UPHILL		DOWNHILL		SOUND LEVELS		
	Q hr^{-1}	H hr^{-1}	Q hr^{-1}	H hr^{-1}	L_{10} dBA	L_{50} dBA	L_{90} dBA
11	590	170	1350	330	85.5	78.5	71.5
12	780	190	1340	290	85.7	79.8	73.0
15	960	360	1720	230	88.1	81.7	75.0
20	1320	340	930	240	85.4	81.0	75.4
30	1050	310	990	200	86.9	80.6	74.4
32	1110	340	1490	460	90.3	84.7	78.4
36	1230	370	1230	370	89.1	82.8	75.9
37	1500	290	1270	310	90.4	82.9	75.6
48	1710	360	1320	270	88.4	83.0	74.9
51	1380	150	1530	210	88.1	80.0	74.5
67	1280	320	1220	100	86.3	79.3	74.5

downhill as well as uphill for purposes of better control. Furthermore, there is a tendency for traffic to travel faster downhill and this increases the tyre noise. Data on rates of flow of uphill and downhill vehicles for all the recordings have thus been omitted, for reasons of economy of space.

10.2 VARIATIONS OF L_{10}.

Because of the larger number of observations taken, variations of L_{10} with rates of flow of traffic were plotted for each site rather than for ranges of gradient, as at first. For reasons given in Section 9.2, L_{10} was plotted as a function of the rate of flow H of heavy vehicles and graphs showing the relationships for each site are provided in Figs. A2.1(a) to (r), Appendix 2. Again it is seen that the variation of L_{10} with H follows the theoretical pattern shown in Fig. 7.1, for d = 15 m. Inspection of these graphs indicates that L_{10} depends on H rather than Q, the total rate of flow. This can be confirmed from Fig. A2.2 in which L_{10} is plotted as a function of Q and percentages of heavy vehicles marked at each point.

For each site the values of L_{10}, when H is greater than 50 hr^{-1} and 4 per cent of the total rate of flow, were normalised to the value corresponding to $H = 325\ hr^{-1}$, using equation 7.9, which may be written more simply as

$$L_{10} = K_1 + H/500 - \log_{10}^{-1}(1 - H/270) \qquad 10.1$$

where K_1 is a constant, being equal to L_{10} when $H = 325\ hr^{-1}$.

The mean of the calculated values for each site together with the standard deviation are displayed in Table 10.2. On each of the graphs shown in Figs. A2.1(a) to (r), the point corresponding to the calculated value of L_{10} when $H = 325\ \mathrm{hr}^{-1}$ was marked and the curve described by equation 10.1 drawn through it. For every one of these curves one finds an even distribution of the points indicating the experimental data. This appears to confirm the validity of the theoretical equation 7.9.

For most of the sites it has been possible to obtain some data for which H is less than $50\ \mathrm{hr}^{-1}$ or 4 per cent of the total rate of flow Q, whichever is the greater, and to which equation 7.8 is applicable. This equation may be expressed more simply as follows:

$$L_{10} = K_2 + Q/500 + 10H/Q - \log_{10}^{-1}(1 - Q/270) \qquad 10.2$$

where K_2 is a constant, being equal to L_{10} when $Q = 1000\ \mathrm{hr}^{-1}$ and $H = 0$. Table 10.3 gives the mean value of L_{10} standardised to $Q = 1000\ \mathrm{hr}^{-1}$ and $H = 0$ for each of the sites where the information was obtainable. To make up for the paucity of data, measurements obtained in the preliminary investigation at sites not used in the current year's work are included.

Figures 10.1 and 10.2 show the variations of the corrected values of L_{10} with gradient obtained from Tables 10.2 and 10.3, respectively. Neither of the two graphs indicate any definite trend in changes of L_{10} with gradient. This may be due to the varying characteristics of the sites but it is difficult to relate these characteristics with the determined values of L_{10} with the information at hand.

TABLE 10.2

MEAN VALUES OF L_{10} FOR RATE OF FLOW H OR HEAVY VEHICLES = 325 hr^{-1} CALCULATED FROM EQUATION 10.1.

Conditions. H $\geq$ 50 hr^{-1} and 4 per cent of the total rate of flow. Values determined at 10 m from kerbside on "uphill" side of road.

SITE NO.	SITE	GRADIENT %	L_{10}(H=325 hr^{-1}) dBA	NO. OF READINGS
16	Uxbridge Road	0.3	78.9 ± 4.3	37
26	Shooters Hill Road (1)	0.4	80.2 ± 3.0	48
38	Upper Ham Road	0.6	81.1 ± 2.7	42
22	High Road, N.Finchley	1.5	77.7 ± 1.2	39
1	Watford Road	2.3	85.5 ± 3.0	32
5	Harrow Road	2.6	78.8 ± 1.4	44
7	Shoot-up Hill	2.9	79.7 ± 4.0	44
28	Shooters Hill Road (2)	3.3	77.1 ± 1.8	30
13	Haverstock Hill	3.6	81.0 ± 2.4	39
47	Balham Hill	4.3	77.9 ± 3.6	22
20	N. Circular Road	5.0	84.9 ± 3.0	68
15	Hanger Lane	6.3	79.9 ± 4.4	55
27	Blackheath Hill (2)	7.6	84.8 ± 3.3	71
31	Gore Hill	8.0	75.0 ± 3.4	30
36	London Road	8.4	76.7 ± 1.7	39
14	Muswell Hill	9.3	81.0 ± 3.0	52
25	Blackheath Hill (1)	9.5	81.0 ± 2.0	48
10	East Heath Road	10.9	79.5 ± 5.1	28

TABLE 10.3.

MEAN VALUES OF L_{10} FOR RATES OF FLOW $Q = 1000\ hr^{-1}$ WITH NO HEAVY VEHICLES (i.e. $H = 0$), CALCULATED FROM EQUATION 10.2.

Conditions. $H < 50\ hr^{-1}$ and 10 per cent of the total rate of flow, whichever is the greater.

Values determined at 10 m from kerbside on "uphill" side of road.

Sites marked * not used in current year's investigation.

SITE NO.	SITE	GRADIENT %	L_{10}(Q=1000 hr^{-1} H = 0)	NO. OF READINGS
16	Uxbridge Road	0.3	71.7 ± 2.4	11
26	Shooters Hill Rd. (1)	0.4	74.4 (± 1.5)	2
7	Shoot-up Hill	2.9	74.7 ± 3.1	6
13	Haverstock Hill	3.6	78.0 ± 3.8	12
20	N.Circular Road +	5.0	76.2 (± 0.4)	2
15	Hanger Lane +	6.3	78.2	1
9	Dartmouth Park Road	7.1	69.7 (± 2)	2
27	Blackheath Hill (2)	7.6	72.7	1
31	Gore Hill +	8.0	64.7 ± 2.4	4
11	EastHeath Road (2)*	9.2	68.7 ± 0.6	8
14	Muswell Hill	9.3	75.2 ± 3.0	18
10	East Heath Road (1)	10.9	76.1 ± 6.6	18
33	Tooting Bec Road*	11.0	79.7	1
32	Amersham Hill*	11.2	73.0 (± 0.1)	2

N.B. Average speed of 45 km hr^{-1} assumed for light vehicles.

Speeds in excess of this experienced at sites marked +.

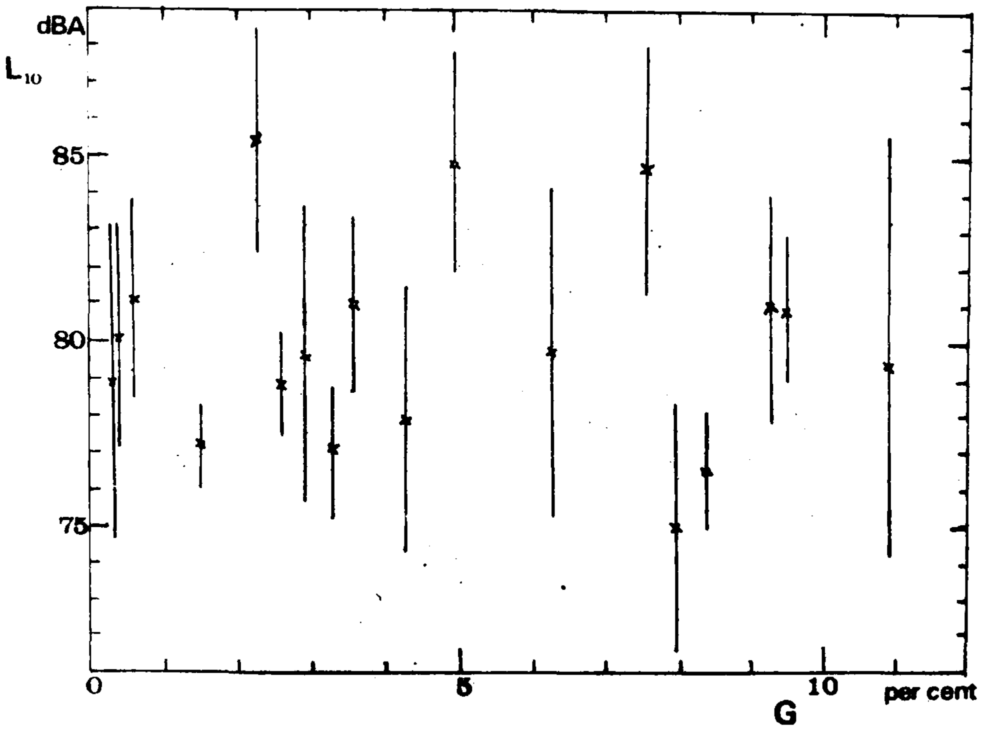

Fig. 10.1. Variation of mean values of L_{10} with gradient G where H = 325 hr^{-1} in accordance with Table 10.2. Vertical lines indicate standard deviations.

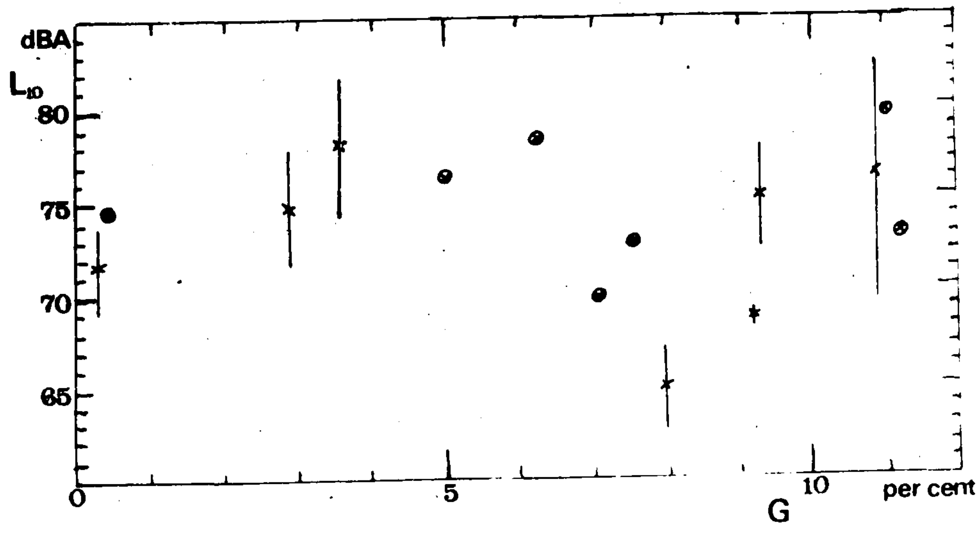

Fig. 10.2. Variation of mean values of L_{10} with gradient G where Q = 1000 hr^{-1} and H = 0 in accordance with Table 10.3. Vertical lines indicate standard deviations. Ringed points indicate insufficient number of readings for applicability of standard deviations.

One would expect L_{10} to be affected by the nature of the environment and the speed of the traffic, i.e. high values for closed aspects and faster than average traffic speeds. Of the three noisiest sites, i.e. Watford Road (1), North Circular Road (20) and Blackheath Hill (27), only Watford Road could be considered to have a closed aspect. On the other hand, at sites such as Balham Hill (47) and London Road (36), which are closed in to some extent by buildings, the standardised values of L_{10} were well below average. Concerning speed, it was found that higher than normal speeds were common at two of the three noisiest locations, i.e. Watford Road (1) and North Circular Road (20) but above average speeds were also frequent at some of the quieter sites, e.g. High Road, North Finchley (22), London Road (36) and Balham Hill (47).

On the other hand, much better correlation has been observed between the standardised values of L_{10} and the numbers of heavy vehicles having 3 or more axles. The high sound levels recorded at North Circular Road (20) could be attributed to the fact that, on an average, some 40 per cent of the heavy vehicles were of this nature. At Blackheath Hill (27) and Watford Road (1) which were also noisy, the near ratios of 3 or more axle trucks to the total numbers of heavy vehicles were 30 and 25 per cent, respectively. An exception to this trend occurred at Gore Hill (31) where the ratio was high and where the heavy vehicles were often driven at speeds between 50 and 60 km hr^{-1} but where the standardised value of L_{10} was only 75 dBA, as compared with about 85 dBA at Blackheath Hill and Watford Road.

A clearer indication of the behaviour of L_{10} with gradient was obtained by means of the technique used in Section 9.2 in which the sites were grouped within ranges of gradient. Within each range it is assumed that there is a sufficient number of sites for which the variations of characteristics due to the surroundings are evened out. Tables 10.4 and 10.5 give the means of the standardised values of L_{10}, for high and low densities, respectively. of heavy vehicles for the different ranges. The corresponding histograms are displayed in Figs. 10.3 and 10.4 respectively.

The histogram for low densities of heavy vehicles (Fig. 10.4) is inconclusive but the one for higher densities, i.e. L_{10} corrected to $H = 325$ hr^{-1} (Fig. 10.3) indicates two alternative possibilities, viz:

(i) L_{10} is not affected in any way by change of gradient.

(ii) Provided that the spread ~~due to~~ of experimental ~~inaccuracies~~ data is disregarded, an initial increase in L_{10} with gradient rising to a peak value for gradients between 4 and 6 per cent is found. For steeper gradients there is a decrease of L_{10} beyond the peak to its initial value when the gradient ranges from 8 to 11 per cent. The peak in L_{10} is 2 dBA higher than the value for zero gradient. Against this, however, must be considered that at North Circular Road where L_{10} has its peak value and which contributes largely to the data within the 4 to 6 per cent range, there are higher than average speeds and an abnormally large percentage of 3-axle heavy vehicles. It should, on the other hand, be mentioned that much gear changing was observed at this site.

TABLE 10.4.

MEAN VALUES OF L_{10} FOR DIFFERENT RANGES OF GRADIENT WHERE $H = 325\ hr^{-1}$, AS OBTAINED FROM TABLE 10.2.

RANGE OF GRADIENT	per cent	0 - 2	2 - 4	4 - 6	6 - 8	> 8
L_{10}	dBA	79.5 ± 3.5	80.5 ± 4.5	81.5 ± 5.5	80.5 ± 6.5	79.5 ± 3.5

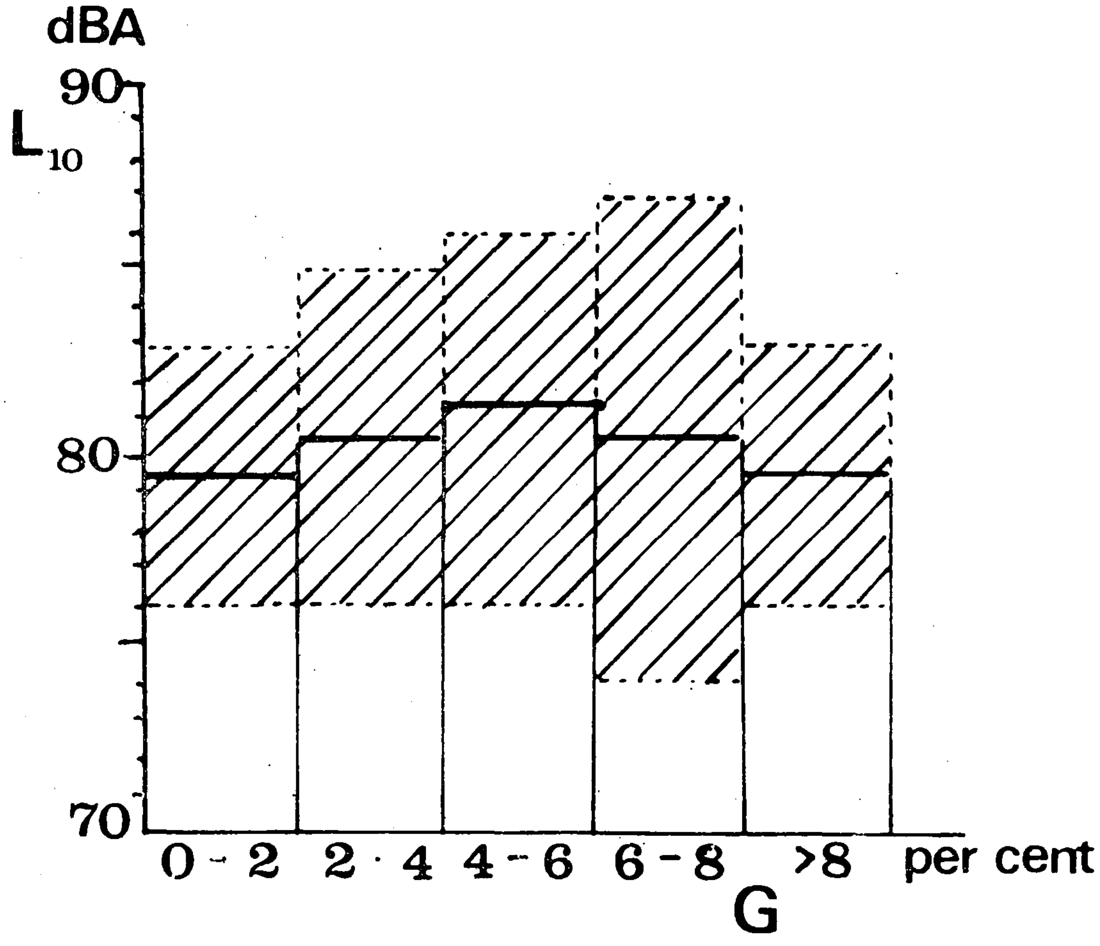

Fig. 10.3. Histogram corresponding to Table 10.4.

TABLE 10.5

MEAN VALUES OF L_{10} FOR DIFFERENT RANGES OF GRADIENT WHERE $Q = 1000\ hr^{-1}$ AND $H = 0$, AS OBTAINED FROM TABLE 10.3.

RANGE OF GRADIENT	per cent	0 - 2	2 - 4	4 - 6	6 - 8	> 8
L_{10}	dBA	72 ± 2	77 ± 3.5	76 (± 0.5)	68 ± 4.5	74.5 ± 3

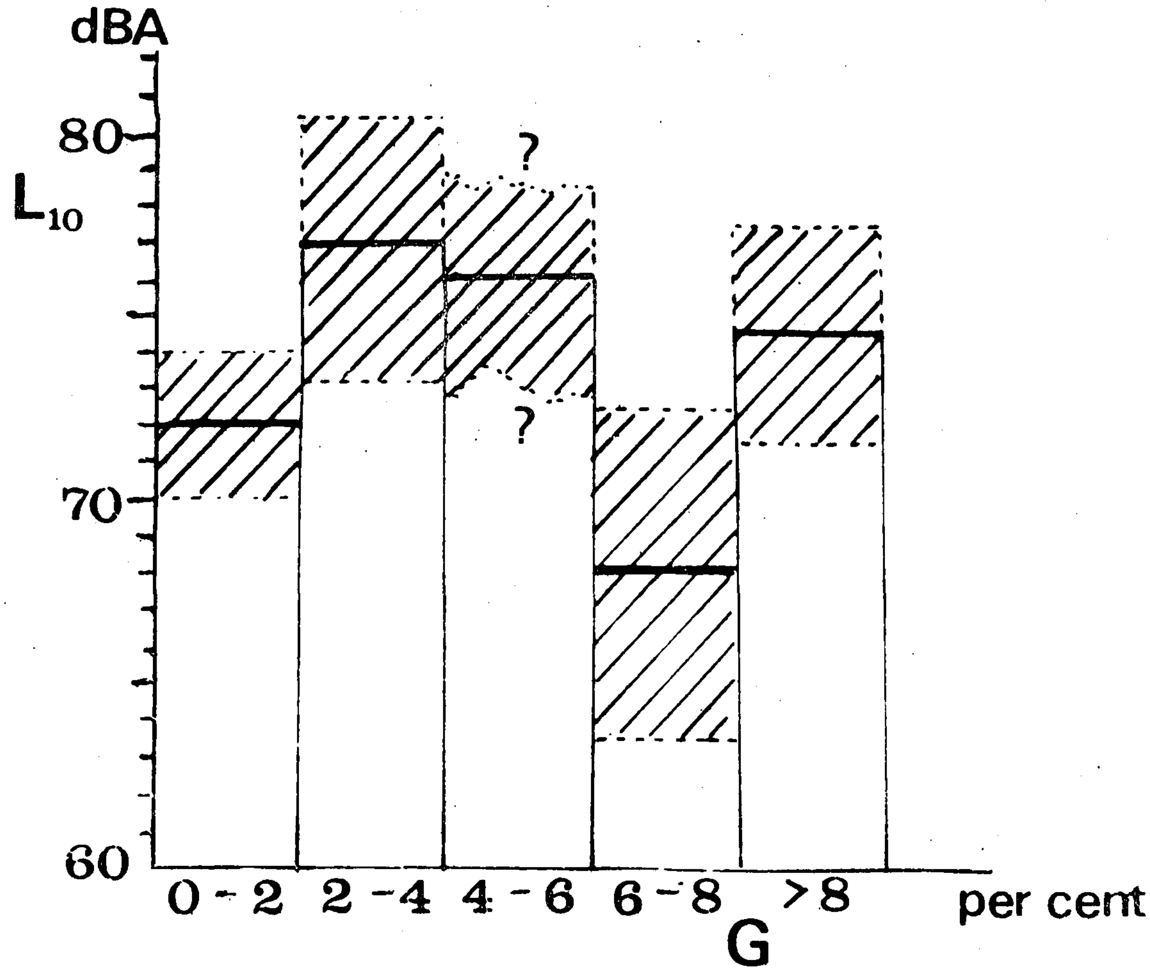

Fig. 10.4. Histogram corresponding to Table 10.5.

On balance it appears that L_{10} in the 10 m position is unaffected by gradient. This confirms the findings given in Section 9.2.

10.3 VARIATIONS OF L_{50}

Following the method employed in Section 9.3, graphs were plotted of L_{50} against the parameter $R = Q + H^2/50$, (see, for example, Fig. A2.3). A high degree of correlation was obtained between L_{50} and R. From these graphs values of L_{50} for $R = 1000\ hr^{-1}$ and $2000\ hr^{-1}$ were read off and tabulated as shown in Table 10.6. Also included in this table are mean values of L_{50} corrected to $R = 1000\ hr^{-1}$, using equation A3.9 in those cases where the equation was approximately valid, i.e. $Q \geqslant 750\ hr^{-1}$ and $H \leqslant 250\ hr^{-1}$. It is seen that the values of L_{50} for $R = 1000\ hr^{-1}$ obtained by calculation and inspection, respectively, are well in agreement with one another.

Fig. 10.5 shows a plot of L_{50} against gradient for $R = 1000\ hr^{-1}$ using the calculated data and, where this was not possible, the data obtained by inspection of the curves. Table 10.7 shows the mean calculated values of L_{50} for different ranges of gradient and Fig.10.6 the corresponding histogram. It appears that L_{50} does not vary with gradient but there is a possibility of an increase of L_{50} from zero gradient to a maximum by 1 dB at about 5 per cent and decreasing to the initial value for gradients over 8 per cent.

10.4 VARIATIONS OF L_{90}

For reasons given in Section 9.4 the determined values of L_{90} were plotted, for each site, in relation to the parameter $R' = Q + H^2/100$ (see, for example Figure A2.4). Table 10.8 displays

TABLE 10.6.

VALUES OF L_{50} OBTAINED

(a) BY INSPECTION OF GRAPHS OF L_{50} AGAINST R

(b) BY CALCULATION OF MEAN VALUES CORRECTED TO R = 1000 hr^{-1}.

SITE NO.	SITE	GRADIENT	VALUES OF L_{50}		
			BY INSPECTION		BY CALC'N
			R = 1000 hr^{-1}	R = 2000 hr^{-1}	R = 1000 hr^{-1}
		%	dBA	dBA	dBA
16	Uxbridge Road	0.3	67	70	66.9 ± 2.6
26	Shooters Hill Rd. (1)	0.4	69	72	68.9 ± 3.4
38	Upper Ham Road	0.6	69	74	68.8 ± 2.0
22	High Rd., N.Finchley	1.5	67	70	67.3 ± 2.6
1	Watford Road	2.3	72	76.5	73.2 ± 2.9
5	Harrow Road	2.6	67.5	70.5	67.4 ± 1.0
7	Shoot-up Hill	2.9	68.5	71.5	67.4 ± 4.2
28	Shooters Hill Rd.(2)	3.3	65	69.9	66.0 ± 1.9
13	Haverstock Hill	3.6	70	73.5	70.2 ± 2.3
47	Balham Hill	4.3	-	71.5	67.5 ± 3.1
20	N.Circular Rd.	5.0	70	74	-
15	Hanger Lane	6.3	72	73	-
27	Blackheath Hill (2)	7.6	70	73.5	71.7 ± 2.8
31	Gore Hill	8.0	64	-	-
36	London Road	8.4	-	68	65.0 ± 1.3
14	Muswell Hill	9.3	67	71	68.1 ± 2.1
25	Blackheath Hill (1)	9.5	-	73.5	69.7 ± 0.6
10	E. Heath Road	10.9	68	-	67.3 ± 4.8

$R = Q + H^2/50$

<u>Conditions for calculated values in column 6</u> $Q \geqslant 750$ hr^{-1} and $H \leqslant 250$ hr^{-1}.

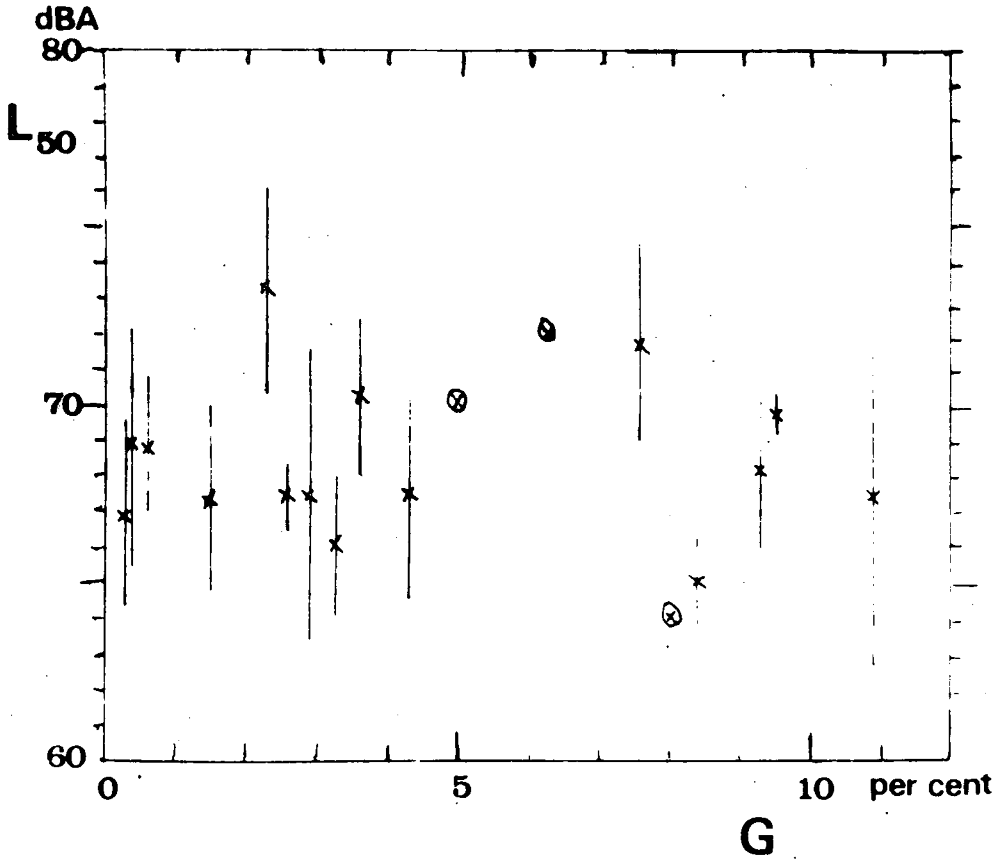

Fig. 10.5. Variation of mean values of L_{50} with gradient G where $R = Q + H^2/50 = 1000\ \text{hr}^{-1}$ in accordance with Table 10.6 (last column). Vertical lines indicate standard deviation. Ringed points indicate values obtained by inspection (columns 4 of Table 10.6).

TABLE 10.7

MEAN VALUES OF L_{50} FOR DIFFERENT RANGES OF GRADIENT FOR R = 1000 hr^{-1}, AS OBTAINED FROM THE CALCULATED DATA OF TABLE 10.6 (LAST COLUMN)

RANGE OF GRADIENT	per cent	0 - 2	2 - 4	4 - 6	6 - 8	> 8
L_{50}	dBA	68 ± 2.5	69 ± 3	69 *	69 *	67.5 ± 2.5

* includes values obtained by inspection (column 4 of Table 10.6) due to paucity of calculated data for which Q $\geqslant$ 750 hr^{-1} and H $\leqslant$ 250 hr^{-1}.

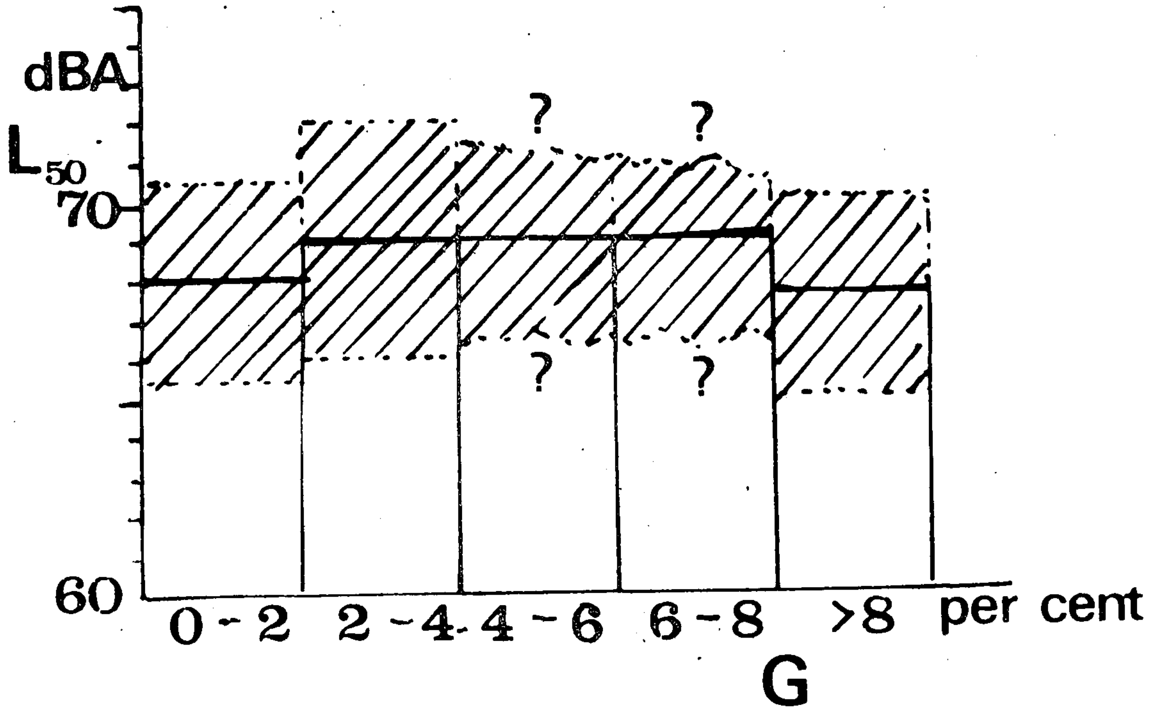

Fig. 10.6. Histogram corresponding to Table 10.7.

TABLE 10.8.

(a) VALUES OF L_{90} OBTAINED BY INSPECTION OF GRAPHS SHOWING VARIATIONS WITH R'.

SITE NO.	SITE	GRADIENT %	VALUES OF L_{90}		
			R'=1000 hr^{-1} dBA	R'=2000 hr^{-1} dBA	R'=3000 hr^{-1} dBA
16	Uxbridge Road	0.3	63	66	68.5
26	Shooters Hill Rd. (1)	0.4	65	68.5	72
38	Upper Ham Road	0.6	64	69	-
22	High Rd. N.Finchley	1.5	61	66	-
1	Watford Road	2.3	66	71	-
5	Harrow Road	2.6	60.5	66	-
7	Shoot-up Hill	2.9	64	69	71
28	Shooters Hill Rd. (2)	3.3	60	66	-
13	Haverstock Hill	3.6	64	69	-
47	Balham Hill	4.3	-	66	73
20	N. Circular Road	5.0	62	68	72
15	Hanger Lane	6.3	67	69	69
27	Blackheath Hill (2)	7.6	61.5	68	73.5
31	Gore Hill	8.0	62	-	-
36	London Road	8.4	60	63	63
14	Muswell Hill	9.3	61	64	66
25	Blackheath Hill (1)	9.5	-	66	68.5
10	E. Heath Road	10.9	62	-	-

$R' = Q + H^2/100.$

(b) AVERAGE VALUES OF L_{90}, AS GIVEN IN ABOVE TABLE, FOR DIFFERENT RANGES, OF GRADIENT.

RANGE OF GRADIENT	per cent	0 - 2	2 - 4	4 - 6	6 - 8	> 8
L_{90} (R'=1000hr^{-1})	dBA	64.5	63	62	63.5	61
L_{90} (R'=2000hr^{-1})	dBA	67.5	68	67	68.5	64.5
L_{90} (R'=3000hr^{-1})	dBA	70	71	72.5	72	66

values of L_{90}, obtained by inspection, for R' = 1000, 2000, 3000 hr^{-1}, as far as possible. Because of the restrictions on the validity of the variation of L_{90} with R', i.e. $Q \geqslant 1500\ hr^{-1}$ and $H \leqslant 125\ hr^{-1}$ it is not feasible to standardise L_{90} for any given value of R'.

No definite indication can be obtained from Tables 10.8(a) and (b) of any variations of L_{90} with gradient for a particular value of R'.

CHAPTER 11.

EXPERIMENTS WITH INDIVIDUAL VEHICLES.

11.1 MEASUREMENTS OF PEAK NOISE LEVELS FROM SPECIFIC VEHICLES.

Road traffic noise levels L_{10}, L_{50}, and L_{90} are dependent on the sounds emitted by vehicles and tests were made on individual vehicles, supplied for the purpose, to determine any relationship between vehicle noise and gradient. Suitable roads were found in the area between Farnham, Hindhead and Milford, Surrey in which the traffic density is very low and where there are a number of hilly roads having stoned asphalt surfaces and with open aspects. It was thus possible to record peak noise levels emitted by the vehicles with little risk of interference from other sources. Any extraneous noises would have required the recording to be repeated but, in practice, this rarely happened.

Recordings were made on two separate occasions, i.e. 1 May and 15 August 1972, both under conditions of fine weather and light winds. Each time a heavy and light vehicle were employed; the same heavy vehicle, a 16-ton laden Ford (1971) articulated 3-axled truck kindly loaned by the Transport and Road Research Laboratory was used on both days but with different drivers; the light vehicles consisted of a Renault 12 TL (1971) saloon car on the first occasion and an Austin A40 (1965) saloon car on the second. During the August tests, additional recordings were made using the heavy vehicle on the test track of the Transport and Road Research Laboratory, to investigate the effects of speeds of heavy vehicles on peak noise levels.

On each occasion the recordings were made, as described in Chapter 8, with the microphone 1.2 m above ground level. During the first set of tests the observations were made 10 m from the roadside. However, because the roads were relatively narrow and variations in their widths could not be ignored in relation to the microphone distance, corrections to the recorded peak sound levels were necessary in order that a proper comparison could be made between different readings. This was avoided with the second set of tests by locating the microphone 10 m from the centre of the vehicle track. In all cases the vehicle was driven past the recording microphone twice in both directions, and the mean uphill and downhill peak levels noted. Variations between the two sets of readings in each direction were found generally to be negligible.

The results of the tests are given in Tables 11.1 and 11.2. The presence of roadworks and other obstructions gave rise to anomalous readings at Tilford (1) and also prevented any recordings being taken at all at Tilford (2) on the second occasions. Conditions were identical at Rushmore and both Hankley Common sites for each test and variations in results can only be attributed to differences in styles of driving, as far as the heavy vehicle is concerned.

Although there appears to be a trend for the vehicle noise level to increase with gradient, it is out of the question to attempt to find any exact relationship between these quantities; any variation will depend on the characteristics of both roads and vehicles as well as the methods of driving. The only reliable way in which one can obtain any sort of relationship is to seek long straight roads of uniform gradients, free from other traffic,

TABLE 11.1.

PEAK SOUND LEVELS OF INDIVIDUAL VEHICLES RECORDED 10 m FROM ROADSIDE ON 1 MAY 1972.

SITE AND MAP REF.	GRAD.	ROAD WIDTH	PEAK SOUND LEVELS					
			HEAVY VEHICLE (FORD)			LIGHT VEHICLE (RENAULT)		
			REC.	MEAN	CORR.	REC.	MEAN	CORR.
	%	m	dBA	dBA	dBA	dBA	dBA	dBA
Rushmore SU873394	2	6.7	81 U (24) 80.5 D (40)	80.5	83	60 (40) 60 D (40)	60	62.5
Tilford (1) SU872434	2.5	5.8	80.5 U (40) 81.5 D (40)	81	83	65 U (40) 61 D (40)	63	65
Hankley Common (1) SU892409	5	3.5	85 U (24) 80.5 D (45)	82.5	84	63 U (40) 62 D (40)	62.5	64
Tilford (2) SU873434	5.5	5.2	80.5 U (40) 80 D (40)	80	82	60.5 U (40) 60.5 D (40)	60.5	62.5
Hankley Common (2) SU819412	10	3.5	91 U (20) 87 D (32)	89	90.5	69 U (32) 69.5 D (40)	69	70.5

N.B. In columns 4 and 7, U = uphill, D = downhill. Figures in brackets indicate speeds in km hr^{-1}.

In columns 6 and 9, corrections made to 10 m from centre of vehicle track.

TABLE 11.2

PEAK SOUND LEVELS OF INDIVIDUAL VEHICLES RECORDED 10m FROM CENTRE OF TRACK.

SITE AND MAP. REF.	GRAD.	PEAK SOUND LEVELS			
		HEAVY VEHICLE (FORD)		LIGHT VEHICLE (AUSTIN)	
		REC.	MEAN	REC.	MEAN
	%	dBA	dBA	dBA	dBA
T.R.R.L. Crowthorne	0	82 (32) 84.5 (40) 86.5 (48) 88.5 (56)			
Rushmore SU873394	2	82.5 U (24) 80 D (32)	81	65 U (40) 62 D (45)	63.5
Tilford (1) SU872434	2.5	80 U (27) 66 D (40)	73	63 U (40) 61 D (40)	62
Hankley Common (1)	5	82.5 U (24) 77.5 D (45)	80 (43)	70 U (48) 66 D	68
Hankley Common (2) SU891412	10	84 U (18) 79 D (45)	82	75 U (43) 68 D (47)	71

N.B. In columns 3 and 5, U = uphill, D = downhill. Figures in brackets indicate speed in km hr^{-1}.

and to take recordings of large samples of different vehicles and drivers. This is almost certainly impracticable and the alternative, which is prohibitively expensive, is to build long straight ramps, having different gradients, specially for the purpose.

The variations of peak noise level with speed, for the 16-ton truck, showed an increase with speed to within 0.5 dBA in accordance with the relationship

$$\Delta L = 30 \log_{10} (v_2/v_1)$$

as predicted by Harland (44).

11.2 MEASUREMENTS OF PEAK NOISE LEVELS OF VEHICLES IN TRAFFIC.

During periods of low traffic densities it may be possible to obtain, from the recordings used to determine L_{10}, L_{50} and L_{90}, peak sound levels of individual passing vehicles. This was done for a number of sites and the data obtained from one of them (Uxbridge Road) is displayed in Table 11.3. The separations of the vehicles from others were sufficiently large for the individual peak noise levels to be free from interference. It is seen that the noise level distribution for light vehicles is approximately normal. For heavy vehicles, the numbers of observations are too few for the type of distribution to be described accurately.

Table 11.4 shows the summarised results of observed peak noise levels from both heavy and light traffic for seven sites. Also shown are the theoretical mean values (i.e. L_{o1} and L_{o2}) calculated from observations of L_{10}, mean speeds and the rates

TABLE 11.3.

PEAK SOUND LEVELS OF INDIVIDUAL VEHICLES AT UXBRIDGE ROAD (16).

LIGHT VEHICLES		HEAVY VEHICLES	
LEVEL	NUMBER	LEVEL	NUMBER
dBA		dBA	
64	2	73	2
65	5	74	0
66	3	75	6
67	5	76	2
68	10	77	0
69	8	78	2
70	21	79	0
71	9	80	1
72	12	81	3
73	4	82	1
74	9	83	0
75	6	84	2
76	6	85	0
77	2	86	1
78	2		
MEAN LEVEL 71 ± 3 dBA		MEAN LEVEL 78 ± 3 dBA	

of flow Q and H of total and heavy traffic respectively, using equations 7.8, 7.8(a), 7.9 and 7.9(a). No apparent variation of mean peak level with gradient is indicated by Table 11.4.

Table 11.4 does, however, confirm the reliability of equations 7.8, 7.8(a), 7.9 and 7.9(a) in predicting values of L_{10} if the determined mean peak sound levels are used for evaluating L_{o1} and L_{o2}. Considering higher densities of heavy traffic which for L_{10} is expressed as a function of L_{o1}, the mean peak value for heavy vehicles, it is seen that there is good agreement for the sites with open aspects, i.e. Uxbridge Road, Shooters Hill Road, Upper Ham Road and Muswell Hill.

With regard to lower densities of heavy traffic for which L_{o2}, the mean peak value for light vehicles, is used in the expression for L_{10}, we again find that there is good agreement for the sites with open aspects, except for Upper Ham Road.

These findings cannot be accepted as being conclusive because the observations of individual vehicles, of necessity, were taken during periods of low traffic densities when the distribution of different types of vehicles within a given class would not necessarily be the same as during periods of high traffic densities.

TABLE 11.4.

MEAN PEAK SOUND LEVELS FOR INDIVIDUAL VEHICLES AT VARIOUS SITES.

SITE	GRAD	MEAN PEAK SOUND LEVELS					
		LIGHT VEHICLES			HEAVY VEHICLES		
		Av. Speed	Obs. Level	Calc. Level (L_{o2})	Av. Speed	Obs. Level	Calc. Level (L_{o1})
	%	km hr^{-1}	dBA	dBA	km hr^{-1}		
Uxbridge Rd. (16)	0.3	45	71 ± 3	70.5 ± 2.5	45	78 ± 3	80 ± 4
Shooters Hill Rd. (26)	0.4	45	73.5 ± 3.5	71 ± 1.5	45	82 ± 5	81 ± 3
Upper Ham Rd. (38)	0.6	45	75 ± 2.5	71 ± 1	40	78 ± 3	81 ± 3
Shoot-up Hill (7)	2.9	40	78 ± 3	72.2 ± 3	40	85 ± 3.5	80 ± 4
Haverstock Hill (13)	3.6	40	73 ± 3.5	75.5 ± 4	35	77 ± 6	80 ± 2.5
Muswell Hill (14)	9.3	45	73.5 ± 3.5	74 ± 3	35	78 ± 4	80 ± 3
E. Heath Rd. (10)	10.9	45	67.5 ± 4	74.5 ± 6	-	-	-

CHAPTER 12.

CONCLUSIONS.

The results of the investigation indicate that L_{10}, L_{50} and L_{90} for road traffic noise observed at 10 m from kerbside and at kerbside are not affected by gradient for urban roads having single carriageways and subjected to speed limits. However, the possibility of increases of L_{10} and, to a lesser extent L_{50}, with gradient up to a maximum of 5 per cent with subsequent decreases for higher gradients cannot be discounted.

A fuller study of the problem requires measurements at a much larger number of sites than investigated at present (e.g. 60 to 100), to even out environmental effects, with much more representation within the range of from 4 to 8 per cent. Suitable sites having uniform gradients within this range with facilities for 10 m from kerbside observations are difficult to find in the London area and it may be necessary to conduct measurements in provincial towns. However, it has been shown, at least for L_{10} and L_{50}, that the differences between kerbside and 10 m from kerbside measurements are reasonably constant and,it may be possible to obtain a sufficiently large number of sites in the London area by means of kerbside recordings with simultaneous recordings at 10 m back, where possible, to serve as a check.

Traffic noise levels at a given position depend on the traffic behaviour at other places along the road, where the gradients may be different and simultaneous recordings at points at roughly equal intervals, e.g. 50 m apart for, say, 500 m are desirable. A check on the effects of the surroundings could be made by conducting measurements simultaneously on both sides of the road.

Values of L_{10}, L_{50} and L_{90} do not appear to be affected by the predominance of uphill or downhill traffic, heavy or light.

A high degree of success has been achieved in relating L_{10} to rate of flow of traffic, theoretically, and it has been shown that, except for low densities of heavy traffic, the value of L_{10} is independent of the rate of flow of light traffic. Good correlation has been obtained between L_{50} and L_{90} and parameters describing the rates of flow of both heavy and light traffic as single quantities.

A limited number of experiments with individual vehicles has not shown any appreciable change in their sound levels with gradient, except for steep gradients (i.e. of the order of 10 per cent). Because of the difficulty and expense of carrying out investigations of this nature there appears to be little point in conducting them further in this direction.

In conclusion it can be said that any variations of traffic noise levels which may be caused by gradients, for a given rate of flow of heavy and light traffic, are generally smaller than those due to differences of traffic behaviour and of the nature of the environment of the various sites.

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APPENDIX 1.

Values of L_{10}, L_{50}, and L_{90} for both kerbside and 10 m from the kerb positions, obtained from the preliminary traffic noise measurements described in Chapter 9, are given in Table A1.1 on the following pages. The data for the various sites, referred to by number and listed below, are presented in ascending order of gradient. Also included are values of ΔL_{10}, ΔL_{50} and ΔL_{90}, the differences between the kerbside and 10 m from the kerb readings for L_{10}, L_{50} and L_{90}.

SITE NO.	LOCATION
1	Watford Road, Sudbury.
2	Sheepcote Road, Harrow.
3	Peterborough Road, Harrow.
4	Sudbury Hill, Sudbury (1).
5	Harrow Road, Wembley.
6	Roxeth Hill, Harrow.
7	Shoot-up Hill, N.W.2.
8	Sudbury Hill, Sudbury (2).
9	Dartmouth Park Hill, N.W.5.
10	East Heath Road, N.W.3. (1).
11	East Heath Road, N.W.3. (2).
12	North End Road, N.W.11.
13	Haverstock Hill, N.W.3.
14	Muswell Hill, N.10.
15	Hanger Lane, W.5.
16	Uxbridge Road, W.5.
17	Star and Garter Hill, Richmond. (1).
18	Star and Garter Hill, Richmond. (2).

19	Archway Road, N.19. (1).
20	North Circular Road, N.2.
21	Falloden Way, N.W.11.
22	High Road, N.12.
23	Priory Road, N.8.
24	Archway Road, N.6. (2).
25	Blackheath Hill, S.E.10. (1).
26	Shooters Hill Road, S.E.10. (1).
27	Blackheath Hill, S.E.10. (2).
28	Shooters Hill Road, S.E.18. (2).
29	Rochester Way, S.E.9.
30	Chesham Road, Amersham.
31	Gore Hill, Amersham.
32	Amersham Hill, High Wycombe.
33	Tooting Bec Road, S.W.17.
35	King's Avenue, S.W.2.
36	London Road, S.E.23.
37	Tulse Hill, S.W.2.
38	Upper Ham Road, Ham.
39	A5, Radlett.
40	Cutenhoe Road, Luton.
41	Eaton Green Road, Luton.
42	Putney Hill.
43,	West Hill, S.W.18.
44	Crowndale, S.E.19.
45	Reigate Hill, Reigate.
46	A23, Redhill.

TABLE A1.1

SOUND LEVELS OBTAINED FROM PRELIMINARY MEASUREMENTS.

SITE NO.	TEST NO	G	W	$\frac{Q}{100}$	$\frac{H}{100}$	$\frac{H}{Q}$	SOUND LEVELS								
							KERBSIDE			10m FROM KERB			DIFFERENCES		
							L_{10}	L_{50}	L_{90}	L_{10}	L_{50}	L_{90}	ΔL_{10}	ΔL_{50}	ΔL_{90}
		%	m	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA
16	1	0·3	11	13	1·6	12	78·3	70·0	61·8	71·2	65·1	57·9	7·1	4·9	3·9
	2			13	1·7	13	79·0	71·5	63·0	—	—	—	—	—	—
	3			14	1·5	11	78·3	71·3	62·5	—	—	—	—	—	—
	4			16	2·2	7	79·5	72·5	64·5	72·0	66·5	61·0	7·9	6·0	4·5
	5			20	1·3	7	79·0	72·0	65·5	71·5	66·0	61·0	7·5	6·0	4·5
	6			15	1·3	9	79·0	71·5	63·0	71·5	65·5	58·5	7·5	6·0	4·5
26	1	0·4	10	17	1·1	13	80·0	72·7	65·2	72·3	66·7	61·7	7·7	6·0	3·5
	2			15	0·2	20	85·2	76·7	68·8	79·8	72·8	68·2	5·4	3·9	0·6
	3			13	2·7	21	80·8	72·1	63·8	—	—	—	—	—	—
	4			15	1·0	15	—	—	—	72·8	66·7	60·7			
38	1	0·6	8	9·5	1·3	14	78·0	68·7	58·3	68·0	61·4	53·5	8·0	7·3	4·8
	2			11	2·0	18	79·3	69·8	60·5	68·6	61·7	54·8	10·7	8·1	5·7
35	1	0·7	10·5	7·3	1·1	15	74·6	62·1	53·2	69·8	60·8	54·1	4·8	1·3	−0·9
	2			7·4	0·5	7	74·2	63·4	53·5	69·0	61·2	53·0	5·2	2·2	0·5
23	1	0·8	10	11	1·5	14	77·3	69·7	62·6	74·3	67·7	60·5	3·0	2·0	1·1
	2			11	1·5	14	75·7	69·0	62·2	73·1	67·5	61·0	2·6	1·5	1·2
21	1	1·2	10	15	5·0	33	84·2	76·0	64·4	76·8	70·2	61·7	7·4	5·8	2·7
	2			18	5·0	28	84·1	75·7	64·1	77·1	71·0	62·3	7·0	4·7	1·8
22	1	1·5	13	10	1·3	13	85·3	76·4	66·5	73·0	65·7	56·5	12·3	10·7	10·0
	2			11	1·3	11	77·7	70·3	61·8	72·7	66·7	59·7	5·0	3·6	2·7
43	1	1·9	9	16	2·0	13	79·5	72·9	65·7	74·8	69·4	63·6	4·7	3·5	2·1
	2			17	2·4	14	79·5	73·0	65·4	76·4	70·6	65·5	3·1	2·4	−0·1

TABLE A1.1 (continued)

SITE NO	TEST NO	G	W	Q/100	H/100	H/Q	SOUND LEVELS								
							KERBSIDE			10m FROM KERB			DIFFERENCES		
							L_{10}	L_{50}	L_{90}	L_{10}	L_{50}	L_{90}	ΔL_{10}	ΔL_{50}	ΔL_{90}
		%	m	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA
1	1	2.3	9.5	13	2.3	18	81.6	72.7	62.7	—	—	—	—	—	—
	2			10	2.2	22	80.4	72.0	61.7	—	—	—	—	—	—
	3			11	2.1	19	80.5	71.2	62.3	—	—	—	—	—	—
	4			11	1.5	14	80.0	70.3	60.0	—	—	—	—	—	—
	5			10	1.4	14	80.2	70.7	60.8	—	—	—	—	—	—
	6			12	2.0	17	81.1	71.3	61.8	—	—	—	—	—	—
	7			10	1.5	15	80.0	71.2	59.7	—	—	—	—	—	—
	11			10	1.6	16	80.1	71.3	60.4	75.5	67.2	57.0	4.6	4.1	3.4
	12			11	1.4	13	80.0	71.6	60.8	76.0	68.2	57.6	4.0	3.4	3.2
29	1	2.4	10	23	3.2	14	76.8	68.0	60.2	69.6	63.7	56.7	7.4	4.3	3.5
	2			16	5.0	31	81.6	73.4	65.3	75.3	67.5	61.8	6.3	59	3.5
	3			15	4.1	27	80.3	72.2	64.8	74.3	68.0	60.5	6.0	4.2	4.3
24	1	2.5	10	19	4.5	24	83.6	76.1	67.8	—	—	—	—	—	—
	2			18	4.1	23	85.7	77.1	68.8	—	—	—	—	—	—
2	1	2.5	6.5	10	1.8	18	82.5	74.3	64.6	—	—	—	—	—	—
	2			9.9	1.6	16	83.3	73.8	64.0	—	—	—	—	—	—
	3			10	1.1	11	85.9	76.0	66.0	—	—	—	—	—	—
	4			9.8	1.5	15	85.4	77.3	67.0	—	—	—	—	—	—
	5			12	1.7	14	87.3	78.7	68.5	—	—	—	—	—	—
	6			9.5	1.5	15	81.2	72.2	63.2	71.7	64.5	580	9.5	7.7	5.2
	7			10	1.3	13	80.8	71.5	61.6	71.7	649	57.8	9.1	6.6	3.8
5	1	2.6	10	7.0	1.1	16	80.0	71.0	62.4	—	—	—	—	—	—
	2			9.0	1.1	12	79.5	71.8	62.8	—	—	—	—	—	—
	3			8.2	2.0	24	79.3	70.0	61.5	74.0	66.0	57.5	5.3	4.0	40
	4			9.0	1.3	1	77.9	70.0	60.0	73.0	65.8	57.5	4.9	4.3	2.5
	5			9.9	1.3	13	78.5	70.5	62.0	—	—	—	—	—	—
	6			10	1.0	10	78.5	71.0	63.0	—	—	—	—	—	—
	7			11	0.5	5	78.5	70.7	63.0	73.5	680	60.3	5.0	2.7	2.7
	8			15	0.6	4	79.0	70.0	630	—	—	—	—	—	—
	9			15	0.7	5	79.0	73.0	65.5	74.0	70.0	64.5	5.0	3.0	2.0
	10			14	1.0	7	78.7	72.5	64.5	73.9	69.5	62.6	4.8	3.0	1.9
7	1	2.9	10	12	2.0	17	79.8	72.5	61.7	70.5	65.7	58.0	7.3	6.8	3.7
	2			13	2.6	20	80.8	73.9	65.3	70.9	65.6	59.4	10.1	8.3	5.9
	3			13	2.1	16	81.0	73.5	63.9	71.8	65.3	58.3	9.2	8.2	5.6
	4			12	2.2	18	78.6	71.5	62.7	71.2	65.6	59.5	7.4	5.9	3.2
	5			15	2.3	15	79.5	72.7	64.5	70.0	66.0	59.5	8.5	6.7	5.0
28	1	3.3	9	9.6	1.0	10	77.5	68.7	61.6	69.8	63.8	57.6	7.7	4.9	4.0
	2			9.8	1.5	15	767	679	60.0	67.5	63.4	55.4	9.2	4.5	4.6

TABLE A1.1 (continued)

SITE NO	TEST NO	G	W	$\frac{Q}{100}$	$\frac{H}{100}$	$\frac{H}{Q}$	SOUND LEVELS								
							KERBSIDE			10m FROM KERB			DIFFERENCES		
							L_{10}	L_{50}	L_{90}	L_{10}	L_{50}	L_{90}	ΔL_{10}	ΔL_{50}	ΔL_{90}
		%	m	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA
37	1	3.5	8	5.4	0.5	9	76.4	69.7	61.2	71.2	61.0	54.2	5.2	8.7	7.0
	2			6.0	1.0	16	76.8	70.7	61.5	72.8	63.8	57.5	4.0	6.9	4.0
13	1	3.6	11	15	0.9	6	76.5	70.5	66.5	74.5	69.5	64.0	2.0	1.0	2.5
	2			16	1.0	6	77.0	72.0	66.0	73.5	69.5	65.0	4.5	2.5	2.0
	3			11	0.4	4	82.5	76.0	71.0	73.5	69.0	64.5	9.0	7.0	6.5
	5			14	0.8	6	77.5	72.5	64.0	72.5	69.0	63.5	5.0	3.5	0.5
42	1	4.2	11	14	1.8	13	80.0	73.0	65.3	–	–	–	–	–	–
	2			15	1.8	12	80.4	73.8	66.8	–	–	–	–	–	–
19	1	4.4	10	14	4.4	31	86.2	77.3	70.0	–	–	–	–	–	–
	2			16	5.4	34	87.5	78.2	71.7	–	–	–	–	–	–
20	1	5.0	9.5	25	3.5	14	83.3	76.2	67.2	76.5	70.1	59.5	5.8	6.1	7.7
	2			24	2.9	12	83.9	76.5	67.2	75.7	69.9	62.0	8.2	6.6	5.2
	3			26	3.6	10	83.8	70.1	68.0	75.2	69.5	66.5	8.6	0.6	1.5
44	1	5.5	8	9.0	1.1	12	76.4	66.8	57.0	72.8	66.0	59.4	3.6	0.8	-2.4
	2			7.7	0.9	12	75.9	65.5	55.9	73.5	65.5	58.3	2.4	0	-2.4
30	1	5.6	9	8.8	1.1	12	78.4	67.9	55.2	70.3	61.3	52.7	8.1	6.6	2.5
	2			9.0	1.2	13	78.4	67.2	56.6	69.8	61.8	53.5	8.6	5.4	3.1
39	1	5.7	9	5.6	1.2	22	77.6	64.7	53.6	67.8	57.1	51.8	9.8	7.6	2.8
	2			4.8	1.3	28	77.6	64.8	56.3	67.6	58.5	52.7	10.0	7.3	3.6
46	1	5.8	11	16	2.1	13	81.1	72.8	65.2	72.2	66.7	61.2	8.9	6.1	4.0
	2			14	1.7	12	82.4	73.7	64.6	74.3	67.9	61.5	8.1	5.9	3.1
15	1	6.3	12.5	28	5.0	18	–	–	–	75.0	69.5	65.0	–	–	–
	2			29	2.6	9	82.5	77.0	71.0	74.0	69.5	65.5	8.5	7.5	5.5
	3			34	4.5	13	83.0	77.5	72.5	74.5	70.0	66.0	10.5	7.5	6.5
	4			33	2.6	8	82.5	77.5	72.0	73.5	69.0	65.5	9.0	8.5	6.5
	5			35	2.1	6	82.0	76.0	70.5	72.0	67.5	64.0	10.0	8.5	6.5
	6			27	5.1	19	83.9	78.1	72.0	75.9	70.7	65.8	8.0	7.4	6.2
	7			28	5.1	18	83.5	77.0	70.5	75.0	69.5	64.5	8.5	7.5	6.0
4	1	6.5	8.5	8.6	0.7	8.5	77.9	69.0	57.8	–	–	–	–	–	–
	2			8.4	0.5	6	78.7	69.8	60.0	–	–	–	–	–	–
40	1	6.7	9	5.8	1.2	21	75.9	63.6	51.0	71.4	60.6	52.0	4.5	3.0	-1.0
	2			11	1.2	11	78.3	64.4	51.3	73.2	61.2	52.5	5.1	3.2	-1.2
3	1	7.0	7.5	5.8	0.4	7	82.3	70.4	60.5	–	–	–	–	–	–

TABLE A1.1 (continued)

SITE NO.	TEST NO.	G	W	$\frac{Q}{100}$	$\frac{H}{100}$	$\frac{H}{Q}$	SOUND LEVELS								
							KERBSIDE			10m FROM KERB			DIFFERENCES		
							L_{10}	L_{50}	L_{90}	L_{10}	L_{50}	L_{90}	ΔL_{10}	ΔL_{50}	ΔL_{90}
		%	m	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA
9	1	7.1	9	7.0	0.7	10	76.0	66.8	58.8	69.2	61.7	55.0	6.8	5.1	3.8
	2			7.0	1.2	17	78.2	66.8	58.7	70.2	62.0	54.7	8.0	4.8	4.0
	3			8.0	5.6	7	76.9	69.6	60.8	68.7	63.8	56.6	8.2	5.8	4.2
	4			10	0.7	7.5	78.1	70.2	62.1	69.9	64.3	599	8.2	5.9	6.2
	5			9.7	0.2	2	77.9	71.0	64.2	69.7	65.1	61.7	8.2	5.9	2.5
	6			13	0.4	3	78.3	72.4	66.3	70.8	66.2	61.4	7.5	6.2	6.9
18	1	7.6	6	10	0.1	1	79.0	68.6	60.4	–	–	–	–	–	–
	2			11	0.2	2	79.3	69.6	60.0	–	–	–	–	–	–
	3			11	0.4	3	78.8	68.4	590	–	–	–	–	–	–
27	1	7.6	13	15	3.5	23	83.5	75.7	67.0	77.7	71.5	63.9	5.8	4.2	3.1
	2			16	2.9	18	84.0	75.7	68.6	77.1	70.0	64.3	6.9	5.7	4.3
45	1	7.7	9	12	1.6	13	82.2	71.7	584	74.6	65.6	52.8	7.6	6.1	5.6
	2			11	1.1	9	79.8	69.3	56.4	74.3	64.2	52.3	5.5	5.1	4.1
31	1	8.0	10	5.5	0.7	13	81.0	67.0	56.5	73.5	63.5	55.5	7.5	3.5	1.0
	2			7.1	0.6	9	79.0	65.3	55.2	72.9	61.6	52.8	6.1	3.7	2.4
36	1	8.4	7.5	18	2.9	16	81.1	73.2	66.0	76.3	70.4	64.2	4.8	2.8	1.8
	2			15	2.0	13	81.2	72.6	65.5	75.5	65.5	58.2	5.7	7.1	7.3
	3			15	3.1	21	–	–	–	74.8	67.7	59.8	–	–	–
17	1	8.8	5.5	7.6	0.9	12	79.3	68.3	58.9	–	–	–	–	–	–
	2			8.3	0.7	9	80.5	70.0	60.8	–	–	–	–	–	–
	4			11	0.3	3	80.8	70.5	60.1	–	–	–	–	–	–
	5			8.0	0.4	5	80.0	69.9	62.3	–	–	–	–	–	–
	V			11	0.7	7	82.3	74.0	63.9	–	–	–	–	–	–
	6			11	0.2	2	79.8	72.4	61.7	–	–	–	–	–	–
	vi			11	0.5	5	80.4	71.2	63.9	–	–	–	–	–	–
	7			8.1	0.2	2	78.0	67.2	59.0	–	–	–	–	–	–
	vii			8.1	0.2	2	78.6	69.2	62.3	–	–	–	–	–	–

TABLE A1.1 (continued)

SITE NO	TEST NO	G	W	$\frac{Q}{100}$	$\frac{H}{100}$	$\frac{H}{Q}$	SOUND LEVELS								
							KERBSIDE			10 m FROM KERB			DIFFERENCES		
							L_{10}	L_{50}	L_{90}	L_{10}	L_{50}	L_{90}	ΔL_{10}	ΔL_{50}	ΔL_{90}
		%	m	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA
11	1	9.2	6	8.0	0.4	5	79.1	68.8	60.4	69.2	62.8	55.9	9.9	6.0	4.5
	2			9.0	0.3	3	79.8	69.3	59.7	68.0	66.8	53.3	1.8	2.5	6.4
	3			12	0.5	5	79.9	71.4	63.8	70.6	64.7	58.7	9.3	6.7	5.1
	4			12	0.3	3	80.2	71.4	63.8	—	—	—	—	—	—
	5			10	0.9	9	78.2	68.8	59.3	68.9	62.7	54.7	9.3	6.1	4.6
	6			7.0	0.6	9	78.2	67.8	58.7	69.3	61.9	53.8	8.9	5.9	4.9
	7			7.5	0.5	7	78.3	67.8	58.3	69.0	61.8	54.2	9.3	6.0	4.1
	8			7.4	0.4	6	78.2	68.5	69.5	68.5	61.2	54.3	9.7	7.3	15.2
	9			7.7	0.3	5	78.2	69.3	61.0	68.8	62.6	56.2	9.4	6.7	4.8
	10			8.1	0.6	7	78.8	69.5	60.7	69.6	63.8	56.0	9.2	5.7	4.7
	11			10	0.3	3	79.0	70.2	61.5	68.3	63.0	55.8	10.7	7.2	5.7
	12			11	0.3	3	79.1	71.7	63.6	69.5	64.6	58.3	9.6	7.1	5.3
12	1	9.2	10	10	0.7	7	78.5	71.5	63.5	–	–	–	–	–	–
	2			10	0.9	9	79.8	72.3	63.9	–	–	–	–	–	–
	3			12	0.7	6	79.0	72.5	64.0	–	–	–	–	–	–
	4			12	0.4	3	80.2	74.1	65.2	–	–	–	–	–	–
	5			12	0.5	4	79.7	73.6	66.7	–	–	–	–	–	–
	6			14	0.6	5	79.5	74.3	67.5	–	–	–	–	–	–
	7			12	0.6	5	74.5	73.5	66.5	–	–	–	–	–	–
14	1	9.3	10	16	1.6	10	–	–	–	75.5	69.5	62.5	–	–	–
	2			15	1.5	10	83.0	74.7	66.1	76.9	69.5	60.2	6.1	5.2	5.9
	3			15	1.5	10	83.8	75.4	66.0	76.0	69.4	60.0	7.3	6.0	6.0
	4			13	1.2	9	82.5	74.0	65.7	69.3	62.3	54.0	13.2	11.7	10.7
	5			13	1.0	8	83.0	74.6	66.4	75.6	68.5	59.8	7.4	6.1	6.6
	6			13	1.2	9	83.2	75.3	67.0	76.3	69.0	61.0	6.9	6.3	6.0
	7			20	0.9	5	83.3	76.7	70.0	76.0	70.9	63.4	7.3	5.8	6.6
	8			16	1.0	6	84.2	75.5	68.0	75.0	69.0	60.7	9.2	6.5	7.3
	9			16	1.0	6	82.5	75.3	67.4	75.6	64.6	62.3	6.9	6.7	4.1
	10			21	1.1	5	83.1	76.5	68.8	73.8	67.2	58.7	9.3	9.3	10.1
	11			22	1.7	3	83.0	76.8	70.2	73.6	67.0	60.5	9.4	9.8	9.7

TABLE A1.1 (concluded).

SITE NO.	TEST NO	G	W	$\frac{Q}{100}$	$\frac{H}{100}$	$\frac{H}{Q}$	SOUND LEVELS								
							KERBSIDE			10 m FROM KERB			DIFFERENCES		
							L_{10}	L_{50}	L_{90}	L_{10}	L_{50}	L_{90}	ΔL_{10}	ΔL_{50}	ΔL_{90}
		%	m	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA	dBA
41	1	9.3	6.5	4.4	0.5	12	74.5	61.0	52.0	69.0	60.0	52.3	5.5	1.0	-0.3
	2			3.8	0.6	16	74.6	61.5	53.0	69.1	60.6	52.7	5.5	0.9	0.3
8	1	9.5	8.5	21	0.3	1	78.2	72.3	67.3	71.2	67.0	61.7	7.0	5.3	5.6
	2			21	0.1	1	78.6	72.5	67.8	—	—	—	—	—	—
	3			8.4	0.6	7	77.3	68.0	58.3	69.7	63.6	56.3	7.6	4.4	2.0
	4			9.5	0.4	4	77.5	68.7	59.3	71.2	64.8	58.2	6.3	3.9	1.1
25	1	9.5	12	14	3.3	23	84.1	75.5	66.9	78.5	72.0	67.7	5.6	3.5	-0.8
	2			16	3.4	21	85.1	76.7	67.8	78.8	72.1	63.9	6.3	4.6	3.9
6	1	10.5	8	4.4	0.3	7	79.2	67.0	58.2	—	—	—	—	—	—
	2			3.6	0.4	13	79.7	66.8	58.0	—	—	—	—	—	—
10	1	10.9	6.5	7.4	0.5	7	77.2	68.8	63.4	67.6	60.3	52.8	9.6	8.5	10.6
	2			9.2	0.5	5	78.0	70.1	63.3	67.8	61.3	54.9	10.2	8.8	8.4
	3			9.2	0.2	2	77.5	69.2	61.9	65.8	60.8	54.1	11.7	8.4	7.8
	4			11	0.4	4	79.8	70.9	62.7	68.2	62.8	55.2	11.6	8.1	7.5
	5			12	0.1	1	78.1	71.2	63.2	66.6	62.0	53.8	11.5	9.2	9.4
	6			12	0.4	3	78.9	72.3	59.9	69.3	63.0	56.7	9.6	9.3	3.2
	7			7.0	0.6	9	77.7	67.9	59.2	66.9	60.0	53.2	10.8	7.9	6.0
	8			8.2	0.6	7	78.7	69.6	59.3	69.8	61.7	54.3	8.9	7.9	5.0
38	1	11.0	10	10	0.3	3	81.3	71.5	62.0	69.2	62.0	55.6	12.1	9.5	6.4
	2			9.6	1.2	13	79.2	70.0	59.5	69.0	63.0	55.9	10.2	7.0	4.0
32	1	11.2	9	12	0.5	4	79.0	71.6	64.3	74.0	67.3	61.0	5.0	4.3	3.3
	2			12	0.5	4	79.5	71.9	64.3	73.7	67.6	59.3	5.8	4.3	5.0

Graphs corresponding to the data given in Table 1 are shown in the diagram below. Fig. A1.1 illustrates the plots of L_{10} and rate of flow H of heavy vehicles for both kerbside and 10 m positions for the five ranges of gradient under consideration. Representative examples of the variations of L_{50} and L_{90} with the parameters R and R', respectively (see equations A3.9 and A3.12) are shown in Figs. A1.2 and A1.3.

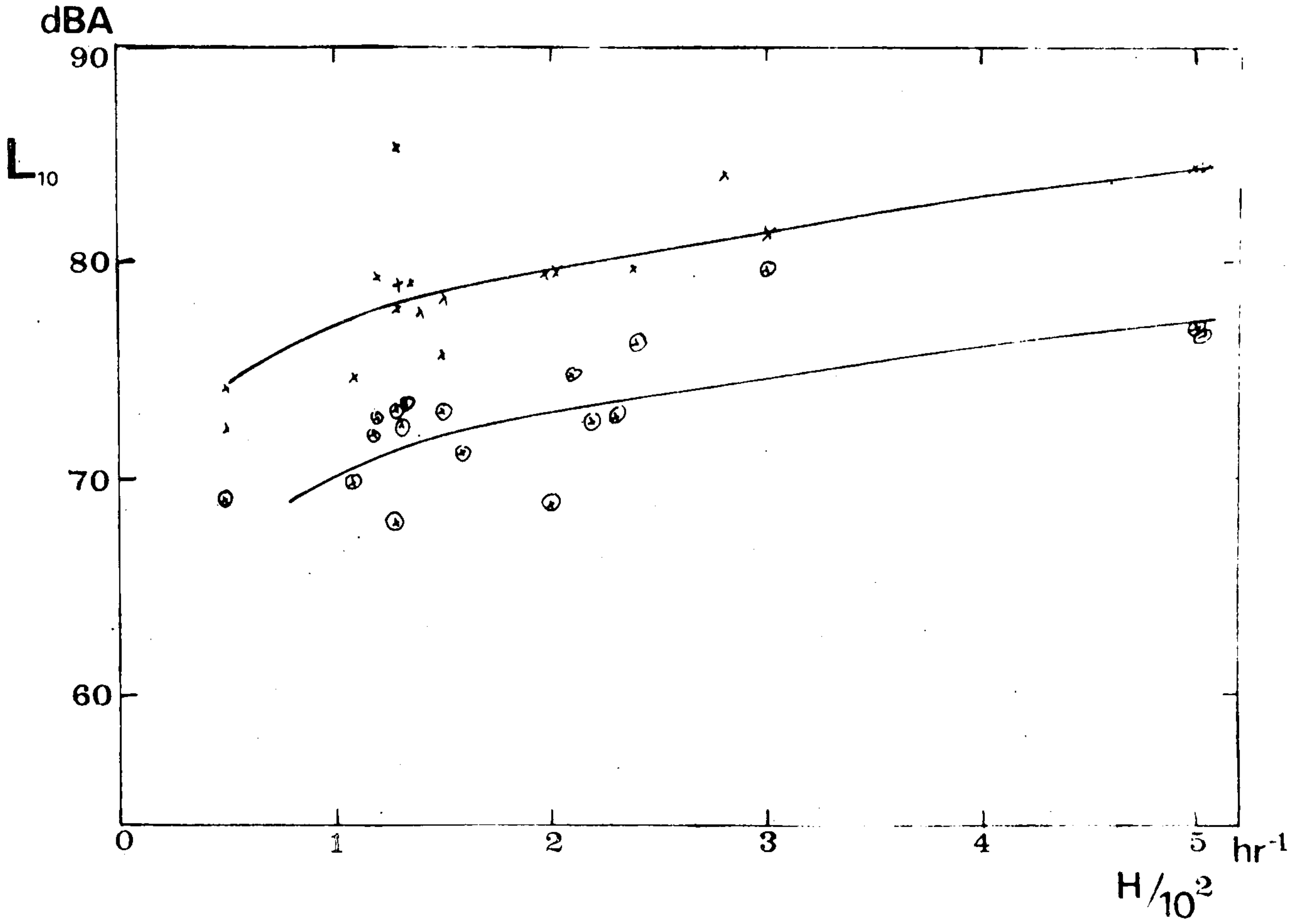


Fig. A1.1(a). Plots of L_{10} with rate of flow H of heavy traffic for kerbside (indicated by ✗) and 10 m from the kerb (indicated by ⊗) for sites having gradients within the range 0 to 2 per cent.

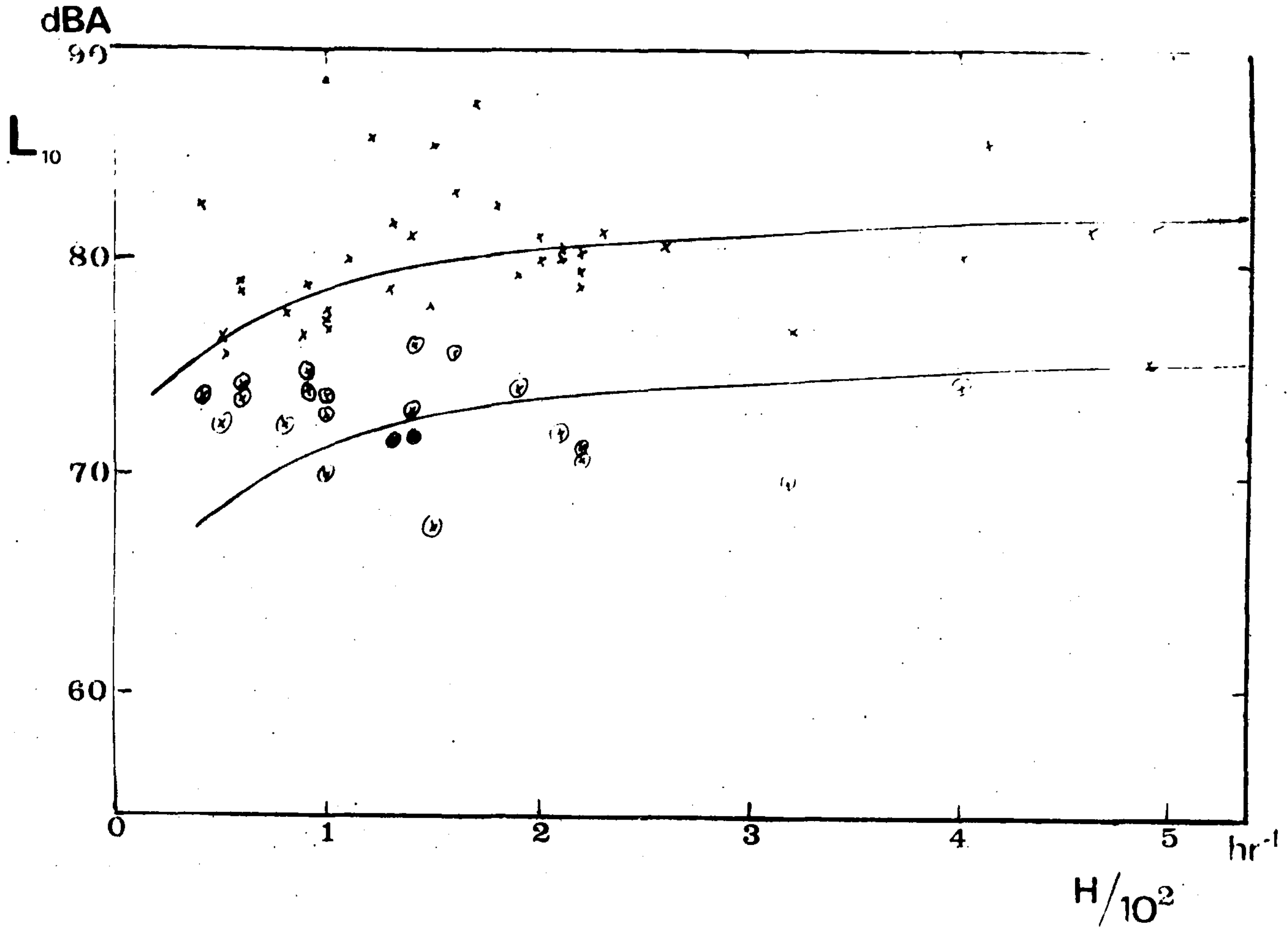


Fig.A1.1(b). Plots of L_{10} with rate of flow H of heavy traffic for kerbside (indicated by ✶) and 10 m from the kerb (indicated by ⊕) for sites having gradients within the range 2 to 4 per cent.

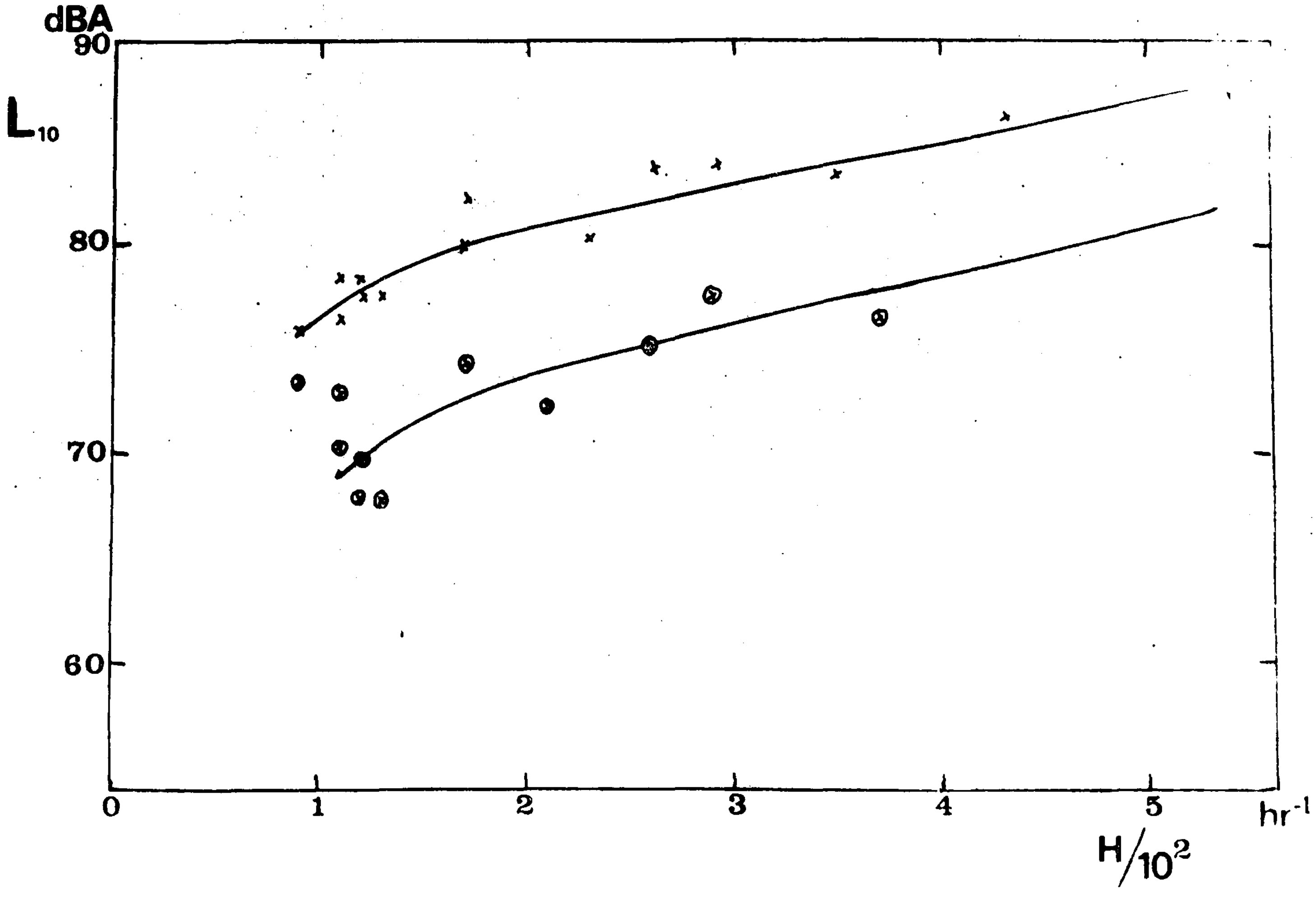


Fig.A1.1(c). Plots of L_{10} with rate of flow H of heavy traffic for kerbside (indicated by ✶) and 10 m from the kerb (indicated by ⊕) for sites having gradients within the range 4 to 6 per cent.

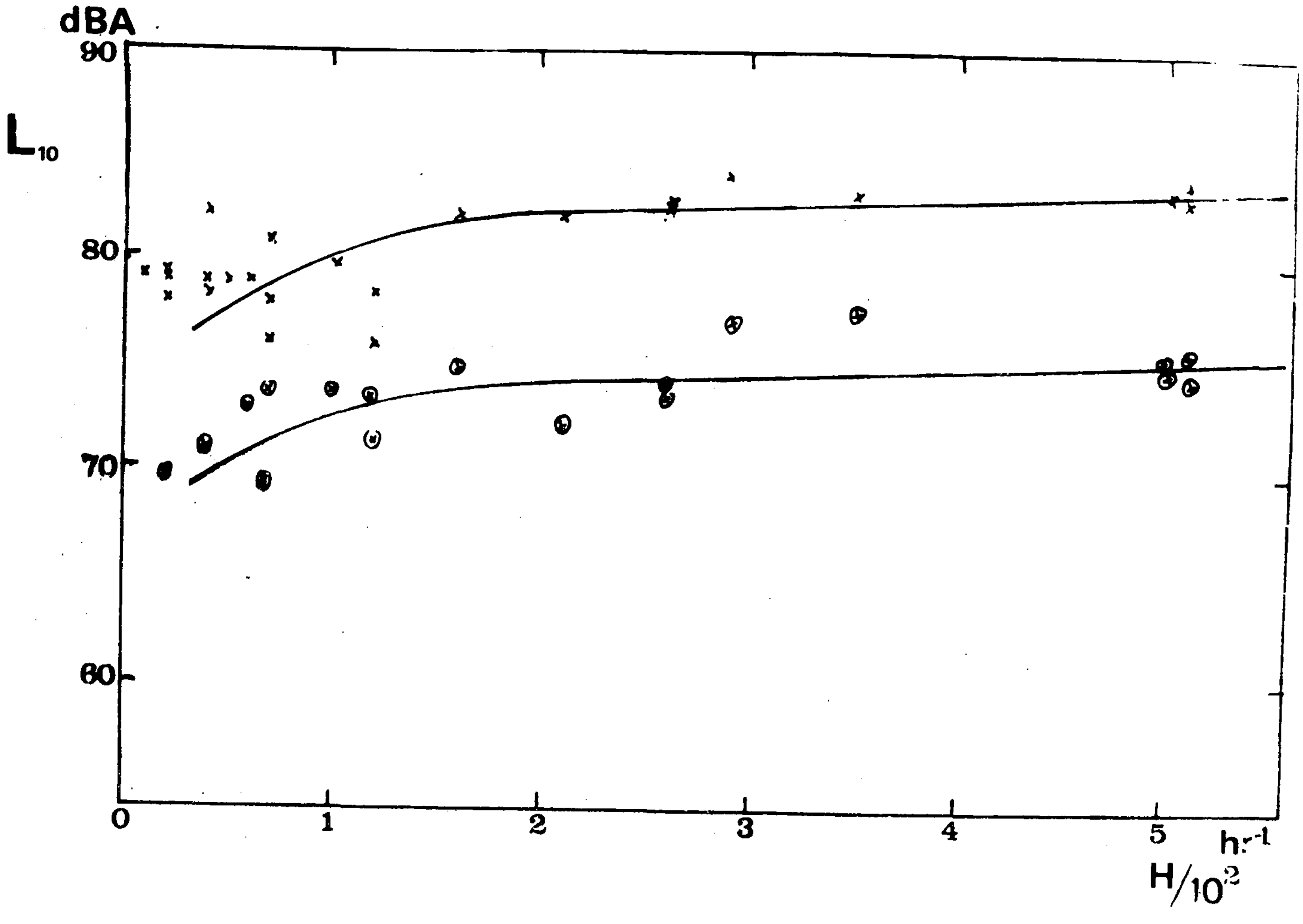


Fig. A1.1(d). Plots of L_{10} with rate of flow H of heavy traffic for kerbside (indicated by +) and 10 m from the kerb (indicated by ⊕) for sites having gradients within the range 6 to 8 per cent.

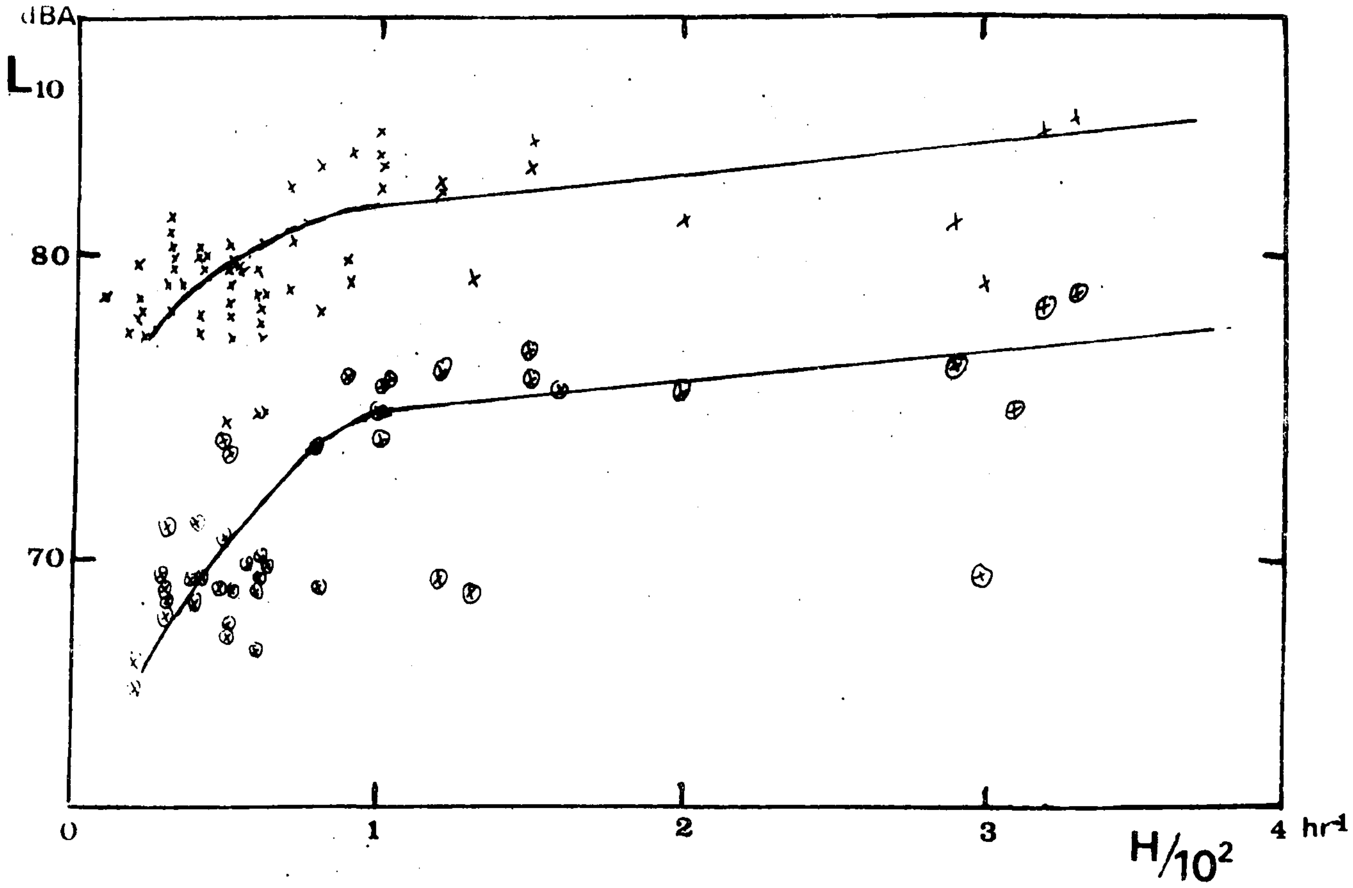


Fig. A1.1(e). Plots of L_{10} with rate of flow H of heavy traffic for kerbside (indicated by +) and 10 m from the kerb (indicated by ⊕) for sites having gradients higher than 8 per cent.

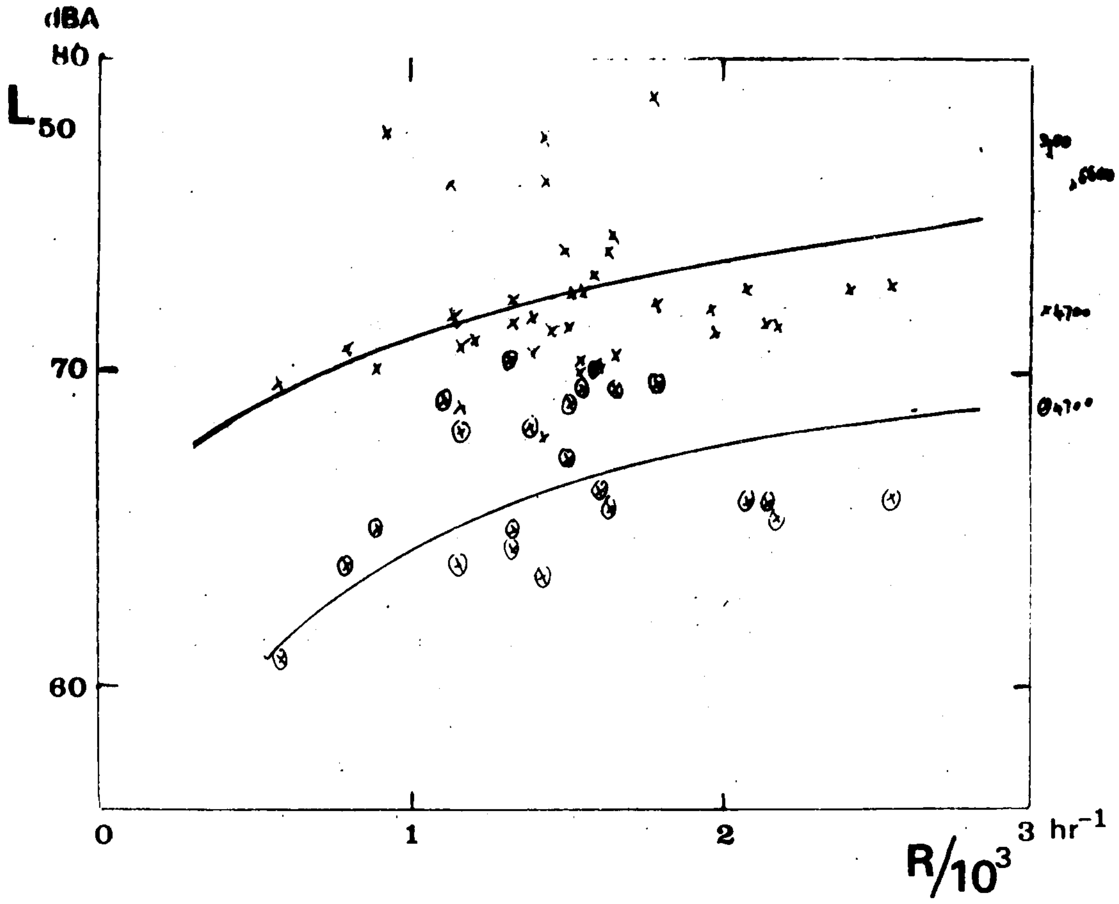


Fig. A1.2. Plots of L_{50} with the parameter $R = Q + H^2/50$ (see equation A3.9) for kerbside (indicated by ✕) and 10 m from the kerb (indicated by ⊗) for sites having gradients between 2 and 4 per cent.

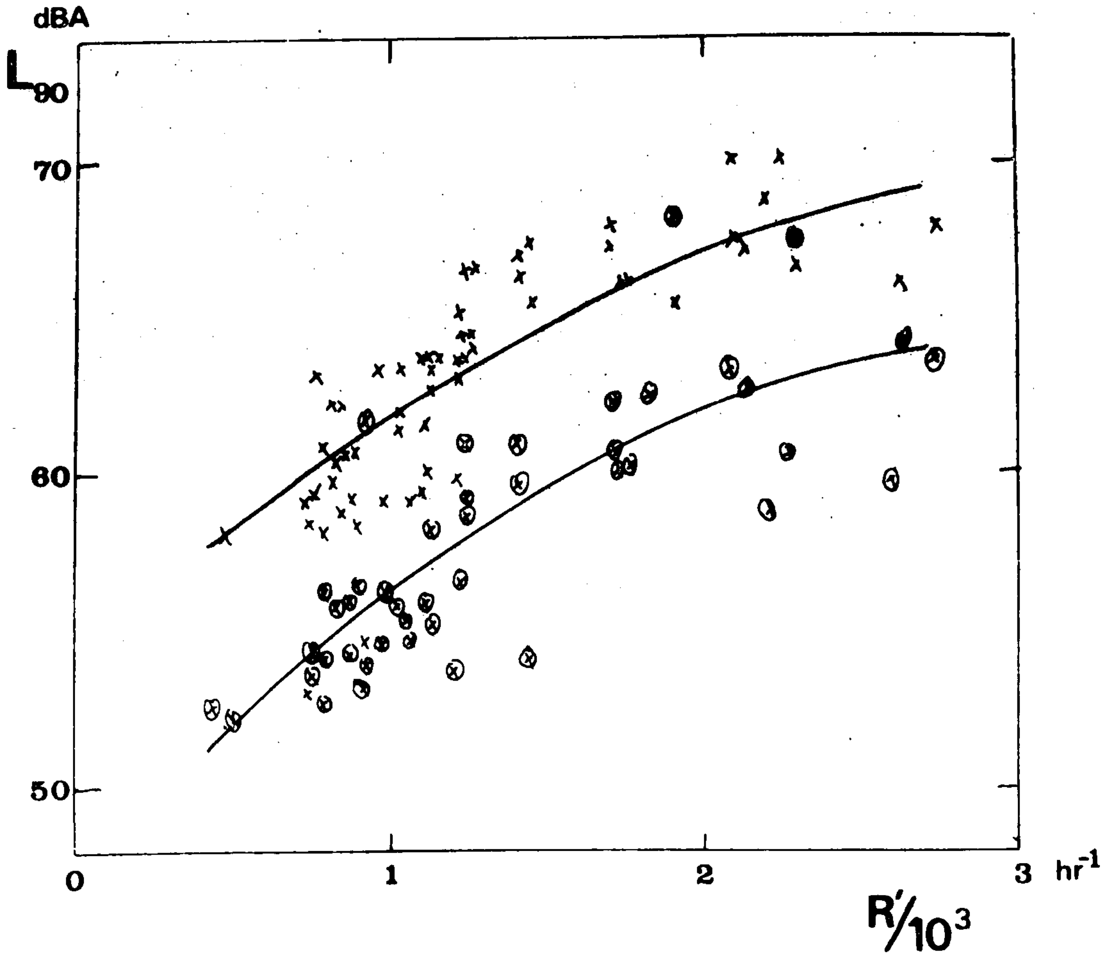


Fig. A1.3. Plots of L_{90} with the parameter $R' = Q + H^2/100$ (see equation A3.12) for kerbside (indicated by ✕) and 10 m from the kerb (indicated by ⊗) for sites having gradients higher than 8 per cent.

APPENDIX 2.

Data concerning the characteristics of the sites and values of L_{10}, L_{50} and L_{90} for different rates of flow obtained during the period April to September 1972 are tabulated in the following pages. (Tables A2.1(a) to (r) in order of gradient.) Measurements were conducted at 18 sites, 17 of which were included in the preliminary investigations. The additional site is Balham Hill (47).

For the sake of completeness, measurements obtained in the preliminary investigation (see Appendix 1) are included. They are identified by means of asterisk (*).

Graphs corresponding to the tabulated data are also given in this appendix. Variations of L_{10} with the rate of flow H of heavy traffic for each of the sites are shown (Figs. A2.1(a) to (r)). For the other variations, only representative graphs are given. These include a plot of L_{10} against Q, showing percentages of heavy traffic for Shooters Hill Road (1) (site No. 26) (Fig. A2.2), and plots of L_{50} and L_{90} against the parameters R (see equation A3.9) and R' (see equation A3.12), respectively, also for Shooters Hill Road (1) (site No.26) (Figs. A2.3 and A2.4).

TABLE A2.1 (a)

16. UXBRIDGE ROAD, W.5.

Gradient 0.3 % Width 11 m Surface Stoned asphalt

Location N. side, by Ealing Common, 250 m W. of Hanger Lane intersection

Characteristics Straight road with four lanes. Very open aspect

Speeds Light vehicles: 40 to 50 km hr^{-1}, reducing to 35 to 45 km hr^{-1} during peak periods
Heavy vehicles: 40 to 45 km hr^{-1}, reducing to 30 to 35 km hr^{-1} during peak periods

Remarks Steady flow, except during peak periods when affected by traffic signals at Hanger Lane and Ealing Broadway. Some gear changing by heavy traffic. Occasional slowing down due to right turns.

Average proportion of heavy vehicles with 3 or more axles 7 per cent.

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	1260	150	12	71.2	65.1	57.9
4*	1580	120	7.5	72.0	66.5	61.0
5+	1990	130	6.5	71.5	64.0	61.0
6*	1500	130	9	71.5	65.8	68.5
7	1270	230	18	75.1	70.1	64.0
8	1200	190	15.5	76.1	70.4	64.9
9	1390	150	11	77.1	70.9	64.7
10	1250	140	11	77.7	71.5	65.4
11	1280	170	14	80.3	74.4	67.9
12	1150	130	11.5	78.8	72.5	65.5
13	40	4	9	59.2	54.7	53.1
14	52	10	19	62.9	55.9	53.5
15	72	14	19.5	68.0	60.0	58.2
16	100	14	13.5	70.5	63.0	59.4
17	180	45	25.5	70.4	61.2	58.1
18	240	57	24	72.7	63.2	59.2
19	430	84	19.5	74.6	66.4	57.7
20	830	96	11.5	82.7	74.2	67.7
21	2280	250	11	78.2	72.6	64.9
22	1880	180	9.5	77.0	71.0	63.0
23	2270	140	6.5	79.6	74.0	66.0
24	2310	160	7	77.0	72.1	67.4
25	2340	84	3.5	79.7	73.5	66.3
26	2270	220	9.5	81.0	75.1	69.1
27	1510	340	25	81.0	75.2	68.7
28	55	9	16.5	63.2	59.1	57.7
29	49	7	14.5	62.4	59.1	57.7
30	127	23	18	66.7	59.8	58.2
31	260	64	24.5	71.3	64.5	63.0
32	1070	120	11.5	70.4	68.7	63.9
33	1490	70	4.5	74.5	68.8	64.4
34	83	13	15.5	65.7	59.5	56.6
35	62	13	21	69.0	63.2	60.4
36	110	27	24.5	70.7	64.3	62.8
37	220	55	25	74.1	64.9	62.6
38	400	75	19	75.8	67.9	63.4
39	630	88	14	83.5	76.4	70.9
40	1200	140	11.5	79.2	72.7	66.1
41	1150	120	10.5	76.5	72.0	66.5
42	1600	170	10.5	78.7	73.5	67.8
43	1590	160	10	82.1	75.9	70.4
44	2160	160	7.5	82.9	76.7	71.3
45	1330	140	10.5	66.5	61.9	56.9
46	1330	160	12	71.4	66.3	61.9
47	1370	140	10	72.0	66.9	63.0
48	1370	150	11	67.8	61.3	57.1
49	1280	130	10	70.4	64.3	59.2
50	1440	80	5.5	71.2	66.6	60.8

TABLE A2.1 (b)

26. SHOOTERS HILL ROAD, S.E.3.

Gradient 0.4 %   **Width** 10 m   **Surface** Stoned asphalt

Location S. side, Blackheath Common, about 0.5 km E. of intersection with Charlton Way

Characteristics Straight road with three lanes. Very open aspect

Speeds Light vehicles: 40 to 50 km hr^{-1}, speeding during off-peak period
Heavy vehicles: 35 to 45 km hr^{-1}

Remarks Steady flow, even during peak hours; no traffic signals for more than 1 km from the site. Noise from traffic at nearby Charlton Way could affect L_{50}

Average proportion of heavy vehicles with 3 or more axles 45 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	1740	220	13	72.3	66.7	61.7
2*	1510	300	20	79.8	72.8	68.2
4*	1480	220	15	72.8	66.7	60.7
5	1480	290	19.5	78.1	72.4	67.4
6	1190	350	30	75.8	70.2	64.7
7	1230	300	24.5	78.6	72.8	66.8
8	1530	310	20	76.5	72.2	65.7
9	1260	360	28.5	78.4	71.8	65.2
10	1370	370	27	78.4	71.8	66.4
11	1700	240	14	78.0	73.0	67.6
12	1560	230	15	78.7	73.7	69.2
13	1670	250	15	78.5	73.1	69.1
14	1990	250	12.5	78.4	72.8	68.4
15	1610	280	17.5	78.4	73.0	68.8
16	2300	250	10.5	79.5	74.0	70.5
17	250	54	21	74.5	63.0	57.2
18	300	57	19	73.4	63.4	57.8
19	760	190	24.5	77.7	68.7	63.4
20	1180	200	17.5	75.7	69.6	63.7
21	1320	280	21	81.0	75.4	69.8
22	1660	280	17	82.1	75.6	70.2
23	2610	320	12	77.7	72.8	68.6
24	2370	280	11.5	77.4	72.6	69.4
25	190	46	23.5	69.5	59.0	55.7
26	·260	51	20	74.0	63.9	57.7

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
27	290	69	24	75.0	65.1	59.2
28	420	68	16.5	73.5	63.9	59.0
29	520	84	16	75.7	66.6	60.6
30	850	210	25	80.2	72.7	66.6
31	1030	210	20.5	79.8	72.3	65.7
32	1600	240	15	79.8	74.1	66.9
33	990	250	25.5	79.9	74.2	69.2
34	1310	200	15.5	80.2	75.4	70.7
35	2660	240	9	80.9	76.2	72.2
36	170	26	15.5	71.6	61.4	58.5
37	290	75	26.5	78.1	67.9	64.3
38	390	110	27.5	78.5	69.5	64.5
39	640	110	17	81.3	74.1	68.3
40	730	200	27.5	83.0	72.8	68.5
41	700	150	21.5	82.2	73.5	66.5
42	810	160	19.5	81.8	74.2	68.3
43	1300	210	16	77.2	70.6	64.9
44	1550	200	13	72.8	65.5	60.2
45	1910	280	14.5	84.5	77.6	71.4
46	2570	210	8	82.5	77.2	72.5
47	2730	210	7.5	82.2	77.7	73.8
48	2800	310	11	85.7	79.4	75.5
49	2570	290	11.5	83.5	77.9	73.2
50	2580	220	8.5	82.7	77.4	72.0
51	2780	210	7.5	82.1	77.5	74.2

TABLE A2.1 (c)

38. UPPER HAM ROAD, HAM.

Gradient 0.6 % **Width** 8 m **Surface** Stoned asphalt

Location E. side, by Ham Common, junction of Church Road (minor road)

Characteristics Straight road. Very open aspect

Speeds Light vehicles: 40 to 50 km hr^{-1}
Heavy vehicles: 40 to 45 km hr^{-1}

Remarks Fairly steady flow, but occasional slowing down by vehicles turning right at intersection 50 m to N. Road too narrow for excessive speeding but occasional overtaking of lorries

Average proportion of heavy vehicles with 3 or more axles 15 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	930	120	13.5	68.0	61.4	53.3
2*	1070	190	18	68.6	61.7	54.8
3	1010	90	9	80.2	73.5	64.3
4	1140	180	16	81.0	75.8	68.0
5	1350	190	14	77.0	70.0	64.0
6	1650	410	25	82.2	75.3	67.2
7	1070	170	15.5	82.0	75.3	67.8
8	1250	150	12	77.1	71.2	64.0
9	1080	110	10	81.5	76.0	69.3
10	1090	220	20	83.4	77.0	69.4
11	40	10	25	67.5	63.7	61.8
12	80	24	30	69.8	63.9	61.8
13	210	76	36	76.5	67.6	64.0
14	270	93	35	78.3	67.7	58.7
15	480	60	12.5	78.3	69.7	66.4
16	1090	150	14	79.4	70.6	65.5
17	1210	130	10.5	79.3	74.7	67.4
18	1440	170	12	79.6	75.2	69.3
19	1510	130	8.5	80.8	76.3	69.8
20	1400	90	6.5	79.0	75.0	69.5
21	1740	120	7	80.8	76.1	70.9
22	1410	150	10.5	78.6	72.5	67.5
23	1200	110	9.2	78.1	71.5	66.0
24	1230	160	13	79.0	72.5	68.5
25	1090	90	8.5	77.7	72.0	67.0
26	1340	110	8	78.6	71.8	66.7
27	1340	150	11	79.3	73.2	68.4
28	1530	60	4	76.2	71.8	74.9
29	1440	70	5	80.5	74.9	68.5
30	1310	110	8.5	80.2	74.5	69.2
31	40	5	12.5	63.4	59.1	57.6
32	67	14	21	65.7	59.4	57.5
33	220	58	27	72.3	62.1	59.3
34	320	82	26	74.7	65.0	62.5
35	470	88	19	76.7	66.4	63.3
36	830	170	20	76.8	68.8	62.9
37	1360	190	14	78.8	70.5	64.5
38	1360	90	6.5	77.3	70.8	64.2
39	23	5	21.5	64.0	61.4	59.0
40	1530	160	10.5	76.5	70.4	64.0
41	230	77	34	74.7	62.8	58.5
42	270	93	34	72.8	61.4	57.4
43	400	88	22	74.8	64.0	59.1
44	670	100	15.5	75.2	65.4	59.5
45	970	140	15	76.2	68.7	62.0
46	1370	110	8	76.8	70.2	64.2
47	1380	120	8.5	76.9	69.7	62.3
48	110	26	24.5	67.2	54.4	57.9

TABLE A2.1 (d)

22. HIGH ROAD NORTH FINCHLEY, N.12

Gradient 1.5 % Width 13 m Surface Stoned asphalt

Location E. side by junction with Addington Drive

Characteristics Very wide straight road, flanked by two-storied buildings but well back from the main road, leaving fairly open aspect

Speeds Light vehicles: 40 to 60 km hr^{-1} but upper limit reduced during peak periods
Heavy vehicles: 40 to 45 km hr^{-1} with occasional speeding

Remarks Fast steady flow with frequent speeding by light vehicles

Average proportion of Heavy vehicles with 3 or more axles 20 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	1020	130	13	73.0	65.7	56.5
2*	1060	110	10.5	72.7	66.7	59.1
3	760	78	10	73.0	66.7	62.3
4	920	140	16	76.0	68.7	63.8
5	1250	140	11.5	75.5	68.6	62.8
6	1340	200	15	75.8	69.9	64.3
7	1270	140	11.5	74.0	67.9	63.9
8	1110	220	20	76.8	69.8	62.3
9	1260	220	17	77.0	70.5	64.0
10	1070	200	18	74.9	70.3	64.1
11	1130	190	17	76.7	70.6	62.2
12	1000	130	13.5	74.9	68.3	59.9
13	1010	150	15	76.4	64.8	63.8
14	1400	200	14.5	77.4	71.1	69.4
15	760	150	20.5	74.9	66.9	59.8
16	900	200	22	76.0	69.5	62.9
17	800	170	21	75.9	68.8	64.0
18	950	200	21.5	77.3	69.5	63.3
19	1030	220	21.5	77.0	69.7	64.0
20	920	200	21.5	76.8	68.8	60.5
21	1100	200	18	70.7	68.8	59.8
22	1010	140	14	74.8	68.7	64.0
23	1030	160	15.5	76.0	68.3	62.7
24	1010	190	18.5	77.3	70.5	61.8
25	980	150	16	74.5	67.7	61.0
26	980	140	14	75.3	68.8	60.0
27	930	110	12	74.7	67.0	59.5
28	990	130	15.5	74.7	68.5	62.3
29	1150	190	16.5	74.8	69.2	62.7
30	930	170	18.5	74.8	67.8	61.0
31	890	130	14	75.0	69.0	62.5
32	890	130	14.5	75.8	69.0	62.0
33	760	140	19	76.5	70.0	61.7
34	950	150	15.5	76.8	70.5	60.5
35	1000	130	13	75.5	69.3	61.8
36	1120	130	11.5	75.5	70.0	63.0
37	1010	170	17	75.3	68.5	61.0
38	1090	130	12	74.6	69.0	61.7
39	1250	160	12.5	77.0	69.8	63.2

TABLE A2.1 (e)

1. WATFORD ROAD, SUDBURY

Gradient 2.3 %   **Width** 9.3 m   **Road surface** Stoned asphalt

Location E. side, by intersection (minor) with Hill Road

Characteristics Flanked on both sides by semi-detached houses, fronting only 7 m from the kerbside

Speeds Light vehicles: 40 to 55 km hr^{-1} with occasional speeding
Heavy vehicles: 40 to 45 km hr^{-1} but come speeding downhill by heavy lorries

Remarks Steady flow at all times. At this point lorries often change gear

Average proportion of heavy vehicles with 3 or more axles 25 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS L_{10}	SOUND LEVELS L_{50}	SOUND LEVELS L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
11*	1040	170	16	75.5	67.2	57.0
12*	1100	140	13	76.0	68.2	57.6
13	1180	130	11	82.5	76.5	69.5
14	1120	150	13.5	85.0	76.3	68.5
15	1180	180	15.5	83.5	76.5	69.0
16	1650	420	25.5	84.8	76.8	68.3
17	1230	210	17	83.5	76.1	69.7
18	1230	150	12	84.5	76.0	70.3
19	1140	170	15	82.5	75.0	68.0
20	1170	110	9.5	84.5	74.8	66.5
21	1350	300	22	83.3	75.5	69.3
22	1510	150	10	83.5	77.0	69.5
23	1130	140	12.5	84.0	75.0	69.5
24	1380	150	11	84.5	78.0	71.5
25	1080	170	15.5	85.0	75.5	69.0
26	1270	210	16.5	85.0	77.5	72.5
27	1270	190	15	85.0	77.5	71.0
28	1260	170	13	81.5	74.5	69.0
29	1230	170	13.5	83.5	75.0	67.5
30	1630	170	10	82.2	76.0	68.3
31	1310	180	14	82.4	74.8	66.2
32	1100	170	15.5	81.2	73.3	65.0
33	1310	180	14.5	79.4	71.7	65.2
34	1150	170	14.5	81.4	74.4	67.5
35	1430	170	11.5	82.9	75.8	68.7
36	1290	120	9.5	82.8	74.7	68.3
37	900	120	13.5	84.4	76.5	69.4
38	1270	180	14	87.0	80.1	71.9
39	1220	150	12.5	85.9	78.6	70.0
40	1120	200	18	88.0	80.0	71.6
41	1150	110	9.5	85.5	79.5	70.3
42	1280	150	11.5	88.8	80.0	71.6

5. HARROW ROAD, WEMBLEY

Gradient 2.6 %   **Width** 10.2 m   **Surface** Stoned asphaly

Location S. side by fire station, 100 m from junction with Crawford Avenue (minor road)

Characteristics Slightly curved road. Flanking two-storied houses well back from road, with wide gaps, leaving fairly open aspect

Speeds Light vehicles: 40 to 50 km hr^{-1}
Heavy vehicles: 40 to 45 km hr^{-1}

Remarks Steady flow at all times; not much gear changing by heavy vehicles

Average proportion of heavy vehicles with 3 or more axles 10 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS L_{10}	SOUND LEVELS L_{50}	SOUND LEVELS L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
3*	810	190	23.5	74.0	66.0	57.5
4*	900	130	14.5	73.0	65.8	57.0
7*	1140	64	5.5	73.5	68.0	60.5
9*	1540	72	4.5	74.0	70.0	64.5
10*	1430	100	7	73.9	69.5	62.6
11	1040	120	11.5	74.6	67.1	59.1
12	1100	70	6.5	74.0	68.6	61.2
13	1130	100	9	75.4	69.4	62.8
14	860	90	10.5	73.9	66.7	59.3
15	1010	80	8	75.3	69.2	62.4
16	860	90	10.5	75.0	68.0	60.9
17	1100	120	11	76.6	70.3	63.5
18	910	110	12	77.0	70.2	63.5
19	800	70	8.5	76.5	73.3	61.1
20	920	60	6.5	73.7	68.0	59.6
21	820	60	7.5	74.1	67.0	59.3
22	1100	110	10	75.8	68.7	60.4
23	1340	150	11	76.2	67.9	59.8
24	730	160	21.5	76.5	68.7	60.4
25	940	150	10	77.3	69.8	62.0
26	1010	120	12	73.3	67.3	59.9
27	830	150	18	76.8	68.5	61.4
28	900	130	14.5	76.3	69.1	63.3
29	970	150	15.5	74.9	67.3	59.5
30	920	90	10	74.9	68.7	60.2
31	890	190	21.5	78.3	69.7	62.9
32	930	110	12	74.5	67.9	61.1
33	830	70	8	74.4	67.4	59.7
34	1010	130	13	76.0	69.3	62.7
35	1190	110	9	75.6	70.3	64.6
36	1100	80	7.5	74.8	68.8	60.9
37	1070	130	12	70.5	69.3	61.4
38	1120	130	11.5	75.3	68.8	62.8
39	900	110	12	73.4	66.9	60.4
40	990	130	13	75.1	67.3	60.6
41	910	90	10	75.1	68.4	62.4
42	920	100	11	74.5	67.3	59.7
43	1030	100	10	73.8	67.4	60.0
44	1060	120	11.5	74.0	67.2	59.8
45	970	60	6	74.1	68.0	59.8
46	900	75	10.5	74.9	68.4	61.7
47	890	80	9	72.9	68.2	60.8
48	1040	130	12.5	74.8	69.1	62.1
49	1170	50	4.5	74.8	69.8	59.9

TABLE A2.1 (g)

7. SHOOT-UP HILL, N.W.2.

Gradient 2.9 % **Width** 9.6 m **Surface** Stoned asphalt

Location W. side, 200 m N. of Kilburn Station, outside Watling Gardens

Characteristics Straight road, flanked by tall blocks of flats with wide gaps in between, but not very open aspect

Speeds Light vehicles: 35 to 45 km hr^{-1}
Heavy vehicles: 30 to 40 km hr^{-1}

Remarks Fairly steady flow but little opportunity for speeding. Much lower gear driving of both heavy and light vehicles because of traffic lights 200 m downhill at Kilburn Station. Occasional congestion in peak hours. Some overtaking of slow lorries. Some downhill decel~~l~~eration in low gear.

Average proportion of heavy vehicles with 3 or more axles 15 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	1220	200	16.5	70.5	65.7	58.0
2*	1260	250	19.5	70.9	65.6	59.4
3*	1300	210	16	71.8	65.3	58.5
4*	1140	210	17.5	71.2	65.6	59.5
5*	1500	220	14.5	71.0	66.0	59.5
6	1390	240	17.5	76.2	70.3	64.2
7	1400	260	19	76.8	71.6	65.7
8	1360	170	13	75.6	71.9	66.5
9	1330	160	12	76.4	70.2	66.2
10	1550	170	11	77.3	71.7	65.0
11	1310	220	16.5	67.8	70.7	65.2
12	140	18	13	68.4	58.4	55.3
13	160	30	19	70.9	57.6	54.2
14	170	44	26	73.4	60.8	57.4
15	240	64	26	67.6	63.4	57.7
16	280	78	28	74.4	59.4	53.5
17	560	100	18.5	75.2	66.7	60.6
18	970	230	24	76.2	70.2	63.5
19	1330	270	20.5	76.2	70.9	67.8
20	1710	280	16	76.5	72.2	65.7
21	1610	250	15.5	76.9	71.3	66.4
22	1940	170	9	76.3	71.1	66.0
23	1670	230	13.5	75.4	70.8	67.3
24	1600	220	14	75.9	70.7	65.7
25	2820	200	7	75.2	70.0	65.3
26	310	81	25.5	72.8	64.2	59.2
27	600	130	22	80.5	73.0	66.6
28	700	150	21.5	81.0	76.1	68.7
29	1150	260	23	81.4	75.4	69.3
30	1240	180	14.5	82.9	76.6	70.5
31	1460	280	19	82.4	76.9	73.8
32	1330	310	23.5	84.0	77.5	73.2
33	1560	160	10.5	82.2	77.4	72.4
34	1560	160	10.5	82.2	76.7	72.4
35	120	14	11.5	72.3	64.5	62.4
36	160	25	15.5	74.5	66.2	62.9
37	210	48	22.5	78.2	68.0	63.8
38	260	50	19.5	76.5	67.5	63.8
39	280	66	24	77.6	68.5	63.9
40	620	130	20.5	80.7	73.5	67.6
41	730	170	23	82.6	75.6	68.6
42	1070	220	20.5	81.3	73.6	66.1
43	1100	290	26.5	83.0	76.8	70.7
44	1370	200	14.5	82.3	77.1	70.4
45	1560	300	19	82.6	77.4	72.9
46	1640	200	12	82.1	75.6	64.5
47	1660	160	9.5	81.6	76.4	70.9
48	1750	170	9.5	81.3	75.6	71.4
49	1790	230	13	83.1	77.5	72.9
50	2020	230	11.5	81.2	76.8	73.7

TABLE A2.1(h)

28 SHOOTERS HILL ROAD, S.E.18

Gradient 3.3 %   **Width** 9.2 m   **Surface** Stoned asphalt

Location N. side, 50 m W. of Corelli Road, 1 km E. of intersection with Academy Road.

Characteristics Straight road with semi-detached houses flanking S. side, and green strip backed by service road and terraced houses to N. side. Fairly open aspect.

Speeds Light vehicles: 40 to 50 km hr^{-1}
Heavy vehicles: 35 to 45 km hr^{-1}

Remarks Steady flow at all times, nearest major intersection 1 km away.

Average proportion of heavy vehicles with 3 or more axles 15 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS L_{10}	SOUND LEVELS L_{50}	SOUND LEVELS L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	960	96	10	64.8	63.8	57.6
2*	980	150	15	69.5	63.4	55.4
3	1160	140	12	73.7	67.2	61.9
4	1040	100	9.5	72.1	65.6	59.4
5	1290	110	8	72.5	67.5	62.3
6	1150	120	10.5	72.5	66.4	61.3
7	1320	110	8	72.2	67.5	63.2
8	950	90	9.5	74.3	68.1	62.2
9	1020	90	9.5	75.8	70.1	64.8
10	1260	90	7	69.7	62.6	58.5
11	1250	60	5	71.3	66.2	62.3
12	990	120	12	74.5	68.3	63.7
13	1030	260	25	75.8	68.2	61.0
14	1020	130	12.5	74.1	67.2	61.9
15	1170	200	17	76.9	70.0	64.5
16	1150	210	18.5	73.2	66.9	60.9
17	1300	170	13	76.1	68.9	61.5
18	1240	130	10.5	73.6	67.9	61.7
19	1320	180	13.5	77.4	71.1	65.7
20	1080	240	22	77.8	70.7	69.9
21	1240	290	23.5	73.5	69.5	62.8
22	1400	210	15.5	78.2	70.5	64.1
23	1040	160	15.5	76.4	69.7	63.7
24	1140	220	19	79.1	70.9	65.3
25	1110	140	12.5	73.9	67.3	60.8
26	1050	120	11.5	74.8	69.1	64.1
27	1270	190	15	75.6	69.1	64.2
28	1040	120	11.5	73.7	63.7	62.5
29	1240	72	6	73.2	67.9	63.5
30	1160	170	14.5	74.9	69.0	62.2

TABLE A2.1 (i)

13. HAVERSTOCK HILL, N.W.3.

Gradient 3.6 % **Width** 11.0 m **Surface** stoned asphalt

Location S.W. side of road by intersection with Belsize Grove

Characteristics Straight road with minor cross-roads at point of observation. Flanked by tall houses, fairly closed-in aspect

Speeds Light vehicles: 40 to 45 km hr^{-1}
Heavy vehicles: 35 to 45 km hr^{-1}

Remarks Usually a steady flow but occasional congestion due to traffic turning right at cross-roads. Much lower gear driving of commercial vehicles. Parked cars tend to inhibit overtaking. Very occasional speeding, usually by sports cars of which a greater than average number.

Average proportion of heavy vehicles with 3 or more axles less than 5 per cent.

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS			TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}					L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA		hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1+	1490	90	6	74.5	69.5	64.0	26	1360	120	9	77.1	69.3	66.4
2+	1620	96	6	73.5	69.5	65.0	27	1540	100	6.5	78.3	76.1	68.7
3+	1050	42	4	73.5	69.0	64.5	28	1410	130	9.5	73.7	69.6	65.2
4+	1380	80	6	72.5	69.0	63.5	29	1310	50	4	80.1	75.2	70.2
5	200	45	21	76.2	67.5	62.7	30	1640	120	7.5	80.2	75.1	71.8
6	200	42	19	81.5	72.6	65.0	31	1760	100	5.5	77.9	73.2	70.3
7	1210	110	11	79.3	75.6	69.0	32	1610	100	6.5	77.3	73.5	70.7
8	120	29	23.5	83.7	72.1	62.2	33	1350	170	12.5	80.1	75.4	71.3
9	310	69	22.5	78.5	67.5	56.8	34	1600	110	7	79.3	74.3	70.9
10	370	36	9.5	79.0	67.5	60.3	35	1120	70	6	77.1	71.6	67.5
11	670	42	6.5	76.0	64.4	61.7	36	1890	100	7	77.9	73.7	68.1
12	830	36	4.5	79.5	71.6	63.8	37	1190	180	10	78.4	72.4	68.7
13	1330	96	7	75.5	69.5	62.7	38	1110	80	14	77.0	73.2	67.9
14	1340	72	5.5	75.7	70.5	66.3	39	1330	150	11.5	78.3	73.7	68.7
15	1640	60	3.5	78.0	73.3	68.2	40	1770	100	5.6	77.9	72.6	67.5
16	1800	120	6.5	74.3	68.7	63.7	41	1520	70	4.5	77.9	73.8	65.2
17	660	100	7	69.0	59.6	48.5	42	1320	180	13.5	78.0	73.1	68.6
18	1370	140	12.5	76.4	72.4	62.4	43	1230	100	8	79.3	72.2	68.6
19	1480	170	11.5	75.8	72.3	65.2	44	1210	90	7.5	77.8	72.7	68.7
20	120	25	21.5	72.7	58.3	56.3	45	99	14	14	67.0	58.1	54.1
21	250	42	16.5	75.4	64.3	55.7	46	150	34	24	71.2	62.5	56.2
22	390	57	14.5	75.7	64.0	58.3	47	1110	50	4.5	74.8	66.4	59.0
23	880	90	11.5	76.8	64.8	58.8	48	1060	80	7.5	75.4	67.9	63.3
24	1310	96	7.5	76.6	71.0	67.8	49	1410	70	5	75.0	70.9	66.3
25	1310	96	7	76.8	72.7	69.3	50	1730	90	7	75.4	72.6	66.3

TABLE A2.1 (j) -

47. BALHAM HILL, S.W.12.

Gradient 4.3 % **Width** 9.0 m **Surface** Stoned asphalt

Location W. side, 100 m N. of intersection with Alderbrook Road, about 400 m S. of Clapham South Station

Characteristics Straight road flanked by flats of medium height on both sides, about 15 m from roadside in each case. Fairly closed-in aspect.

Speeds: Light vehicles: 45 to 60 km hr^{-1} downhill, 40 to 50 km hr^{-1} uphill
Heavy vehicles: 40 to 50 km hr^{-1} downhill, with occasional speeding and 35 to 45 km hr^{-1} uphill

Remarks Steady flow even during peak hours. Not much gear changing

Average proportion of heavy vehicles with 3 or more axles 10 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1	1690	290	17	81.1	76.5	72.0
2	1650	270	16.5	84.5	78.5	75.0
3	1630	250	15.5	74.0	68.7	64.1
4	1570	240	15	75.4	68.7	62.7
5	1250	180	14.5	75.3	69.4	62.0
6	1610	170	10.5	74.5	70.0	64.5
7	1600	290	18	73.7	69.3	64.0
8	1420	360	25.5	75.0	70.0	64.5
9	1530	270	17.5	75.9	71.2	66.7
10	1810	300	16.5	78.5	73.3	69.3
11	1610	270	17	75.1	69.8	63.8
12	1710	250	14.5	77.8	74.2	66.1
13	1800	290	16	79.6	70.7	67.8
14	1400	180	13	78.6	72.3	69.0
15	1510	180	12	75.5	69.1	64.2
16	1680	180	10.5	74.7	70.1	66.1
17	1530	120	8	74.1	70.1	65.2
18	1540	120	8	73.7	68.0	61.9
19	1220	240	19.5	77.7	71.4	66.1
20	1530	240	15.5	70.9	65.2	59.6
21	1680	310	19	82.3	76.5	70.8
22	1790	230	12.5	87.2	80.2	74.0

TABLE A2.1 (k)

20. NORTH CIRCULAR ROAD, N.3.

Gradient 5.0 % Width 9.5 m Surface Stoned asphalt

Location N. side, by corner of Amberdeen Avenue, 0.8 km W. of East End Road roundabout

Characteristics Long straight incline with 3 lanes, two of which used mainly by uphill traffic. Very open aspect.

Speeds Light vehicles: 60 to 80 km hr^{-1}, reducing to 40 to 60 km hr^{-1} during peak periods.
Heavy vehicles: 35 to 45 km hr^{-1} uphill, 40 to 65 km hr^{-1} downhill.

Remarks Usually a steady flow but uphill traffic tends to slow down considerably during peak periods due to congestion at the East End Road roundabout. Much gear changing by heavy traffic.

Average proportion of heavy vehicles having 3 or more axles 40 per cent

Table of data on the next page.

TABLE A2.1 (k) (continued)

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	2540	360	14	76.5	70.7	59.5
2*	2410	290	12	75.7	69.9	62.0
3	2620	270	10.5	75.2	69.5	66.5
4	150	48	32.5	74.5	62.9	58.9
5	150	48	32	75.0	62.1	58.6
6	330	130	40	78.2	70.6	69.9
7	570	140	25.5	79.8	69.5	62.2
8	970	320	33	83.4	74.5	66.4
9	930	260	28	79.6	71.9	59.9
10	1260	350	28	84.4	76.0	69.8
11	1940	500	25.5	85.5	78.5	71.0
12	2120	480	22.5	85.7	79.8	73.0
13	1840	390	21	85.2	77.9	71.2
14	2410	450	18.5	86.4	79.5	72.1
15	2680	590	22	88.1	81.7	75.0
16	2500	420	17	85.0	78.9	72.7
17	2110	600	18.5	85.2	79.0	72.0
18	2340	600	25.5	88.5	81.9	76.2
19	2450	580	23.5	85.4	80.6	75.3
20	2250	580	26	86.6	81.0	75.4
21	2740	600	22	87.2	80.4	73.8
22	2150	480	22.5	85.5	79.9	73.1
23	100	65	64.5	77.8	64.6	62.6
24	110	53	49	72.1	68.2	64.0
25	2170	590	27	87.6	81.7	74.7
26	2320	590	25.5	87.4	81.4	75.7
27	2060	590	28.5	93.9	87.4	82.5
28	2220	660	28.8	89.5	83.2	76.8
29	2230	560	25	88.1	81.7	75.2
30	2040	510	25	86.9	80.6	74.4
31	2220	630	28.5	88.8	82.9	77.0
32	2600	800	31	90.3	84.7	78.4
33	2140	610	28.5	86.0	76.1	69.0
34	2040	560	27.5	89.1	81.7	74.2
35	3950	1280	32.5	89.4	82.0	75.5
36	2460	740	30	89.1	82.8	75.9
37	2770	600	21.5	90.4	82.9	75.6
38	2390	660	27.5	87.4	79.6	74.0
39	2810	820	29	87.4	80.2	74.8
40	2450	630	25.5	88.0	82.0	75.2
41	2840	620	22	84.4	79.3	73.4
42	2580	600	25	85.5	81.1	77.1
43	2760	520	19	87.5	71.7	76.7
44	2480	420	17	84.9	79.7	72.9
45	2480	600	24	86.5	80.5	72.5
46	3160	600	19	84.6	79.7	74.7
47	2400	300	12.5	86.6	80.2	75.5
48	3030	630	21	88.4	83.0	74.9
49	2560	340	13.5	83.9	76.4	70.1
50	2460	420	17	86.5	78.8	71.5
51	2910	360	12.5	88.1	80.0	74.5
52	410	160	40	79.8	68.2	63.9
53	560	190	34	82.5	72.7	66.6
54	500	200	39.5	84.2	73.6	66.6
55	770	360	46.5	84.4	74.4	67.2
56	940	290	31	84.5	75.9	68.7
57	1110	390	35	86.9	77.5	70.8
58	1540	480	31.5	83.6	76.8	70.6
59	1250	370	30	84.5	76.4	62.3
60	1750	480	27.5	87.4	79.0	72.5
61	1970	550	28	84.5	77.9	72.0
62	1980	400	20	89.8	80.2	71.5
63	2200	580	26.5	89.1	81.1	72.8
64	2760	580	21	87.0	81.5	77.8
65	3150	570	18	87.6	79.4	73.2

TABLE A2.1 (1)

48. HANGER LANE, W.5 (NORTH CIRCULAR ROAD)

Gradient 6.3 % Width 12.3 m Surface Stoned asphalt

Location W. side 50 m S. of junction with Chatsworth Road (N. part) 500 m S. of intersection with Western Avenue.

Characteristics Straight road with 4 lanes, curving slightly at the summit of the hill 200 m further N. Spinney on side of observer and large park opposite. Very open aspect.

Speeds Light vehicles: 40 to 50 km hr^{-1} uphill, 45 to 60 km hr^{-1} downhill, with reductions during peak hours. Heavy vehicles: 35 to 45 km hr^{-1} uphill, 45 to 55 km hr^{-1} downhill.

Remarks Usually a steady flow. Much gear changing. Occasional slowing down due to right turning traffic at summit. Sometimes peak hour congestion caused by traffic lights at Western Avenue.

Average proportion of heavy vehicles with 3 or more axles 30 per cent

Table of data on next page.

TABLE A2.1 (1) (continued)

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1 *	2800	500	18	75.0	69.5	65.0
2 *	2940	280	9	74.0	69.5	65.5
3 *	3390	430	13	74.5	70.0	66.0
4 *	3290	270	8	73.5	69.0	65.5
5 *	3470	230	6	72.0	67.5	64.0
6 *	2750	520	19	75.9	70.7	65.8
7 *	2790	490	18.5	75.0	69.5	64.5
8	2920	450	15.5	81.5	76.3	71.2
9	2600	450	17.5	80.4	76.0	70.9
10	2780	420	15	81.9	76.7	71.7
11	3140	500	16	79.2	75.1	70.9
12	2840	400	14	79.2	74.1	70.1
13	3210	350	11	79.9	75.7	72.2
14	2860	470	16.5	82.4	76.1	70.7
15	3270	530	16	86.2	80.3	74.7
16	3170	530	16.5	85.0	76.3	72.2
17	2760	570	20.5	83.1	78.5	74.1
18	2980	560	19	84.4	78.6	74.2
19	2980	460	15.5	83.5	77.6	72.9
20	2960	580	19.5	81.2	76.2	71.8
21	3070	560	18	80.3	74.3	69.6
22	360	84	23.5	81.7	71.4	67.3
23	200	57	28	85.3	73.4	69.2
24	180	72	40.5	79.5	70.0	68.3
25	180	87	48.5	76.4	64.9	63.0
26	150	57	37.5	76.5	64.7	62.6
27	250	93	36.5	88.4	77.1	73.6
28	320	29	29	79.5	68.2	61.4
29	540	170	31	82.1	71.6	64.7
30	540	190	32.5	85.4	75.5	66.7
31	950	310	32.5	87.4	77.1	68.6
32	1280	370	29	87.4	78.4	71.1
33	130	41	32.5	76.4	64.7	62.6
34	160	50	30.5	78.3	66.9	63.4
35	190	57	29.5	76.5	64.9	62.6
36	2520	440	17.5	77.0	72.5	65.8
37	3180	440	14	77.5	72.4	67.1
38	3450	630	18.5	78.6	74.5	70.6
39	3020	720	24	79.2	74.0	69.0
40	3040	460	15	78.8	72.7	67.2
41	3080	600	19.5	81.0	74.8	70.5
42	3000	400	13.5	75.5	72.0	67.7
43	2780	460	16.5	78.5	73.2	69.7
44	2920	420	14.5	76.9	72.1	69.1
45	3810	540	14	77.9	73.5	70.6
46	2970	360	12	78.8	73.5	69.8
47	2820	620	22	80.2	74.2	68.7
48	2660	560	21	78.8	72.7	66.5
49	2760	640	23	79.5	73.5	66.8
50	3120	480	15.5	77.5	72.3	67.0
51	2460	520	21	79.6	73.8	70.4
52	2640	400	15	77.7	72.5	66.4
53	3100	480	15.5	76.5	72.1	68.8
54	3100	460	15	77.7	72.1	66.6
55	3160	660	21	78.2	74.8	71.1
56	3150	480	15	77.3	72.9	69.4

TABLE A2.1 (m)

27. BLACKHEATH HILL, S.E.10

Gradient 7.6 % Width 12.9 m Surface Stoned asphalt

Location N. side, 200 m E. of intersection with Lewisham Road, opposite the "Horse and Groom".

Characteristics Slightly curved road with 4 lanes. Flanked on both sides by blocks of flats, set back from the road, but with gaps in between. Public house fronts directly on to pavement. Fairly open aspect.

Speeds Light vehicles: 40 to 55 km hr^{-1} in both directions
Heavy vehicles: 35 to 45 km hr^{-1} uphill, 40 to 50 km hr^{-1} downhill. Downhill traffic slower during peak hours due to traffic signals at bottom of hill.

Remarks Usually a steady flow with occasional overtaking. Some decel~~l~~eration of downhill traffic.

Table of data on next page.

TABLE A2.1 (m) (continued)

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1 *	1510	350	23	77.7	71.5	63.9
2 *	1600	290	18	77.1	70.0	64.3
3	1630	390	24	86.7	81.1	72.4
4	1860	390	21	89.2	82.2	75.2
5	1790	510	28.5	88.7	80.4	72.3
6	1510	350	23	86.3	79.2	72.3
7	1730	430	25	89.0	82.0	70.7
8	1490	290	19	88.5	82.0	74.9
9	1670	350	20.5	89.0	82.6	75.6
10	1790	430	24.5	88.0	81.8	74.4
11	1750	250	14.5	85.7	79.6	73.4
12	1620	480	29.5	88.5	81.5	74.8
13	1610	390	24.5	88.4	81.0	74.9
14	1510	470	30.5	89.7	83.2	77.6
15	1860	240	13	87.4	81.6	75.2
16	1680	300	18	85.5	79.9	74.4
17	2010	430	21.5	90.6	84.2	78.4
18	1950	390	20	85.3	80.1	73.3
19	2000	360	18	85.4	79.6	74.5
20	1550	300	19.5	88.1	81.5	75.5
21	2010	510	25.5	89.4	82.4	74.0
22	1800	430	24	88.2	82.8	74.8
23	1630	330	20	86.7	81.1	76.3
24	1700	250	15	84.9	80.9	72.7
25	1700	410	24	87.7	81.2	72.0
26	1910	370	19.5	84.9	79.5	74.0
27	1620	300	18.5	86.7	80.2	74.6
28	1430	300	21	86.5	80.3	70.0
29	1770	360	20.5	86.9	77.4	69.6
30	1860	360	19.5	86.8	80.5	74.3
31	1930	360	18.5	87.0	81.1	74.9
32	1700	370	22	85.8	79.6	72.4
33	1700	340	23	89.5	82.2	75.0
34	1750	270	15.5	88.0	80.2	75.4
35	1920	350	18	88.9	82.4	77.1
36	1800	300	16.5	86.4	80.2	69.7
37	1650	190	12	87.9	80.8	74.6
38	1350	270	20	87.5	79.6	73.2
39	1790	290	16	83.5	78.2	71.0
40	1670	300	18	83.9	77.5	68.6
41	1600	290	18	81.6	75.2	68.0
42	1810	310	17.5	86.9	80.3	71.9
43	1920	460	24	87.4	83.5	79.0
44	1940	380	19.5	88.9	82.9	77.4
45	1940	360	18.5	84.5	80.2	74.9
46	1710	310	18.5	87.3	80.6	74.3
47	1940	220	11.5	84.5	74.9	73.3
48	1920	420	22	92.5	85.2	77.1
49	230	42	18.5	72.5	60.5	57.7
50	350	91	26	76.9	65.8	58.8
51	790	130	16	77.3	70.6	61.4
52	630	110	17	78.4	69.8	60.3
53	810	170	21	78.6	71.0	61.2
54	920	220	24	78.5	70.7	60.0
55	1030	220	21.5	79.5	72.3	63.4
56	1180	310	26.5	84.5	78.2	67.0
57	1190	170	14	82.5	74.5	73.1
58	1590	360	22.5	83.9	77.0	65.2
59	2010	240	12	81.6	77.1	71.0
60	1850	300	16	74.2	74.0	67.9
61	2020	360	18	82.1	77.3	71.8
62	2370	410	15	81.6	76.6	70.4
63	2720	420	15.5	80.5	75.9	72.6
64	3060	360	12	82.1	77.0	73.0
65	2860	400	14	80.8	77.1	73.2
66	2820	340	12	83.9	79.4	73.1
67	3270	210	6.5	81.3	77.2	74.0
68	2760	270	10	83.5	78.6	74.2
69	2680	420	15.5	83.0	75.2	74.5
70	2880	340	13.5	83.1	77.7	74.3
71	2760	240	8.5	80.6	76.3	73.0
72	2730	240	9	78.6	75.1	72.2

TABLE A2.1 (n)

31. GORE HILL, AMERSHAM (A 404)

Gradient 8.0 % **Width** 10 m **Surface** Stoned asphalt

Location E. side, 1 km S. of intersection, in Amersham Village with the Uxbridge-Aylesbury Road

Characteristics Country road with very open aspect

Speeds Light vehicles: 40 to 60 km hr^{-1} uphill, 50 to 70 km hr^{-1} downhill.
Heavy vehicles: 35 to 50 km hr^{-1} uphill, 40 to 60 km hr^{-1} downhill.

Remarks Steady flow, no congestion. Frequent gear changing.

Average proportion of heavy vehicles with 3 or more axles 30 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	550	68	12.5	73.5	63.5	55.5
2*	710	60	8.5	72.9	61.6	52.8
3	440	84	19	73.1	64.9	61.2
4	520	84	16	70.8	62.1	58.1
5	510	64	12.5	71.8	63.7	59.5
6	490	92	18.5	72.4	63.7	59.2
7	440	80	18.5	69.1	54.6	56.6
8	460	80	17.5	65.2	58.3	54.8
9	540	92	17	68.3	59.4	56.2
10	480	84	17.5	66.0	57.5	53.3
11	620	77	12.5	74.7	64.6	60.0
12	550	60	11	73.8	65.0	63.5
13	740	130	18	78.4	68.6	62.7
14	520	110	21	73.4	64.7	63.1
15	390	86	22.5	70.5	63.3	59.6
16	400	93	23.5	73.0	64.2	61.3
17	420	76	23.5	70.7	64.6	63.0
18	390	97	25	70.7	63.6	60.5
19	500	90	18	72.8	64.6	63.0
20	590	73	12.5	72.6	64.8	63.1
21	740	120	16	71.8	64.0	60.3
22	590	130	22.5	73.0	64.8	63.1
23	490	70	14.5	64.2	57.0	53.8
24	620	100	16.5	65.8	58.2	53.9
25	620	60	9.5	63.8	56.8	53.6
26	600	88	14.5	65.4	58.2	54.5
27	620	72	11.5	70.8	63.9	60.8
28	720	110	16	67.4	59.4	57.1
29	620	42	6.5	63.8	56.6	53.6
30	770	67	8.5	65.5	58.8	55.2
31	780	33	4.5	64.1	57.6	53.8
32	1040	30	3	62.3	58.6	55.3
33	760	52	7	65.9	59.3	56.7
34	610	6	1	67.8	62.3	59.0

36. LONDON ROAD, S.E.23 (SOUTH CIRCULAR ROAD)

Gradient 8.4 % **Width** 10.7 m **Surface** Stoned asphalt

Location S. side, corner of Park Hill, almost opposite the Horniman Museum. 500 m W. of Forest Hill Station.

Characteristics Straight road with slight curve to E. Flanked on both sides by blocks of flats set back from the road. Fairly closed-in aspect.

Speeds Light vehicles: 40 to 50 km hr^{-1} in both directions.
Heavy vehicles: 35 to 45 km hr^{-1} uphill, 40 to 50 km hr^{-1} downhill.

Remarks Steady flow; most heavy vehicles and some light vehicles driven uphill in lower gears.

Average proportion of heavy vehicles with 3 or more axles 20 per cent.

TEST NUMBER	Q	H	H/Q	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	1830	250	15.5	76.3	70.4	64.2
2*	1460	180	12.5	75.5	65.5	58.2
3*	1480	310	20.5	74.8	67.7	59.8
4	1450	210	14.5	75.0	69.8	66.4
5	1300	260	19.5	75.5	68.8	64.2
6	1380	300	21.5	77.8	70.9	64.7
7	1310	310	24	78.8	70.4	64.3
8	1530	300	19.5	74.9	69.8	63.2
9	1360	230	17	75.9	69.2	63.4
10	1440	240	16.5	73.6	69.1	60.5
11	1620	290	17.5	77.7	69.9	60.0
12	1550	230	14.5	78.5	68.4	62.8
13	1510	250	17	71.1	65.4	58.6
14	1530	180	12	74.0	68.5	64.1
15	1760	260	15	78.0	71.3	63.9
16	1410	190	14	74.8	68.5	64.5
17	1560	180	11.5	74.7	69.4	65.0
18	1370	270	19.5	77.0	70.0	65.2
19	1430	230	15.5	75.6	69.8	62.8
20	1510	180	12	74.8	68.2	60.8
21	1260	230	18	79.6	69.7	62.0
22	1440	210	14.5	76.6	69.2	64.5
23	1800	100	5.5	75.0	69.8	63.8
24	1670	250	15.5	75.5	68.6	62.7
25	1630	190	12	77.0	70.8	64.5
26	1490	210	14	77.1	70.7	64.5
27	1810	270	15	77.5	70.0	64.9
28	1680	190	11.5	76.2	69.9	64.6
29	1270	230	17.5	75.9	68.6	62.2
30	1760	240	13.5	75.2	69.4	63.8
31	1390	150	11	76.0	69.1	61.2
32	1680	180	10.5	75.2	68.4	63.0
33	1710	210	12.5	77.2	69.7	63.5
34	2020	160	8	73.6	68.8	64.5
35	1630	240	14.5	75.1	68.6	59.9
36	2020	220	11	75.1	69.0	63.1
37	2240	260	11.5	74.0	69.3	64.3
38	1880	100	5.5	73.0	67.7	64.2
39	1850	290	15.5	74.8	70.0	66.3

TABLE A2.1 (p)

14. MUSWELL HILL, N.10

Gradient 9.3 % Width 10.0 m Surface Stoned asphalt

Location S.W. side by corner of Rookfield Avenue, 200 m N.W. of intersection with Priory Road.

Characteristics Straight road with 3 lanes, two of which used mainly by uphill traffic. Woodlands to N.E. side and two-storied houses with small gardens to S.W.

Speeds Light vehicles: 40 to 50 km hr^{-1} uphill and downhill
Heavy vehicles: 25 to 40 km hr^{-1} uphill, 35 to 50 km hr^{-1} downhill.

Remarks Steady flow at all times. Most vehicles in lower gear uphill, and heavy vehicles usually in lower gear downhill Frequent overtaking by cars uphill. Speeding rare.

Average proportion of heavy vehicles with 3 or more axles 5 per cent.

Table of data on next page.

TABLE A2.1 (p) (continued)

TEST NUMBER	Q	H	H/Q	SOUND LEVELS L10	SOUND LEVELS L50	SOUND LEVELS L90
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	1590	160	10	75.5	69.5	62.5
2*	1470	140	10	76.9	69.5	60.2
3*	1480	150	10	76.0	69.4	60.0
4*	1290	120	9	69.3	62.3	54.0
5*	1320	100	8	75.6	68.5	59.8
6*	1320	120	9	76.3	69.0	61.0
7*	2010	88	4.5	76.0	70.9	63.4
8*	1610	96	6	75.0	69.0	60.7
9*	1560	100	6	75.6	69.6	62.3
10*	2100	100	5	73.8	67.2	58.7
11*	2200	80	3.5	73.6	67.0	60.5
12	1400	200	14.5	79.3	72.1	64.7
13	1380	280	20.5	78.7	70.7	63.6
14	1220	150	12.5	77.7	70.8	64.3
15	1390	180	13	77.9	70.8	64.6
16	1350	180	13.5	77.0	70.7	64.6
17	1400	180	13	78.4	71.5	64.8
18	1350	140	10.5	76.8	69.3	62.8
19	1530	150	10	78.3	72.7	65.0
20	1480	130	9	78.6	72.4	66.0
21	1460	150	10	76.6	70.0	62.7
22	1160	170	14.5	73.0	64.8	57.9
23	1620	200	12.5	77.7	71.3	64.5
24	1270	140	11	78.5	71.7	64.0
25	1550	70	4.5	77.2	72.0	65.1
26	1460	140	9.5	77.0	70.7	64.3
27	1260	140	11	75.3	68.7	60.2
28	1510	160	10.5	76.5	70.1	63.0
29	1480	70	4.5	82.7	64.0	63.7
30	1620	160	10	73.3	67.2	60.4
31	1630	140	8.5	77.6	73.1	64.4
32	1470	110	7.5	78.3	71.5	64.5
33	1880	210	11	80.6	73.2	61.1
34	1000	78	8	78.0	71.4	64.8
35	1480	50	3.5	77.7	71.7	64.3
36	2120	140	6.5	78.5	73.6	67.8
37	1980	120	6	78.8	73.0	67.1
38	1890	90	5	78.8	72.8	67.1
39	2280	140	6	79.6	74.1	65.8
40	1970	130	7	78.6	74.0	67.9
41	1970	190	10	80.2	73.8	67.0
42	2030	75	3.5	78.9	73.1	67.2
43	2670	100	3.5	78.1	73.4	65.5
44	2300	70	3	78.7	74.0	69.4
45	2280	100	4.5	79.9	74.1	65.8
46	2550	30	1	80.1	74.4	68.4
47	2900	100	3.5	77.9	72.9	67.4
48	2420	100	4	78.7	72.8	65.6
49	2020	84	4	78.3	73.3	65.4
50	2040	60	3	78.6	73.0	67.0
51	1910	45	2.5	77.8	72.6	67.5
52	2010	45	2	77.8	72.3	67.0
53	2040	30	1.5	76.6	71.6	66.5
54	1750	60	3.5	81.0	71.0	64.6
55	1680	75	4.5	77.2	72.1	65.0
56	1830	15	1	77.8	72.6	65.6
57	1650	15	1	76.3	70.6	64.6
58	1520	12	1	75.5	70.3	64.4
59	92	15	16.5	64.8	60.7	58.4
60	250	32	13.5	70.2	59.8	58.2
61	370	50	13.5	72.9	62.9	58.9
62	72	0	18	64.8	61.6	59.0
63	100	3	17	70.4	61.5	55.2

TABLE A2.1 (q)

25. BLACKHEATH HILL, S.E.10.

Gradient 9.5 % **Width** 10.0m **Surface** Stoned asphalt

Location N. side by corner of Holly Mount, 150 m W. of E. end of Shooters Hill Road.

Characteristics Straight road with 3 lanes, 2 of which used mainly by uphill traffic. Flanked by tall houses, closed-in aspect.

Speeds Light vehicles: 35 to 45 km hr^{-1} uphill, 40 to 50 km hr^{-1} downhill.
Heavy vehicles: 20 to 40 km hr^{-1} uphill, 30 to 45 km hr^{-1} downhill.

Remarks Usually a steady flow. Road narrows to 2 lanes 100 m further uphill. Heavy vehicles, invariably in low gear and cars mainly in low gear. Occasional congestion due to slow heavy lorries.

Average proportion of heavy vehicles with 3 or more axles 25 per cent.

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS			TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}					L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA		hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1 *	1400	320	23	73.5	72.0	64.7	25	1590	410	25.5	81.2	75.9	66.1
2 *	1620	340	21	78.8	72.1	63.9	26	1610	370	23.5	80.0	75.1	63.3
3	2060	360	17.5	80.5	75.1	70.7	27	1790	180	10	79.8	72.8	64.0
4	1920	460	24	82.1	76.2	64.6	28	1820	260	14.5	80.2	73.0	65.5
5	1600	460	29	84.3	78.0	69.9	29	1670	270	16	79.7	73.9	67.5
6	1960	340	17.5	86.0	79.7	75.7	30	1490	300	20	79.5	73.0	65.0
7	1400	240	17	81.9	75.8	70.1	31	1620	220	13.5	79.5	73.5	68.0
8	1880	460	24.5	85.8	78.6	72.7	32	1820	380	21	80.8	73.5	64.5
9	1530	410	25.5	83.7	76.2	67.6	33	2060	580	28	83.0	73.9	71.2
10	1740	260	15	79.1	73.7	65.0	34	1400	370	27	80.7	74.3	68.5
11	1710	390	23	81.2	75.4	690	35	1440	480	33.5	80.7	75.7	66.8
12	1860	300	16	78.1	73.5	68.8	36	1840	440	24	80.3	74.5	66.5
13	1840	200	11	77.6	78.4	69.5	37	1880	480	25.5	80.8	74.0	66.8
14	1510	350	23	81.3	75.8	64.2	38	2060	440	21.5	81.2	74.5	67.1
15	1770	360	20.5	82.5	75.8	68.2	39	1840	340	18.5	83.0	75.5	70.5
16	1620	240	15	83.1	75.7	69.4	40	1550	230	14.5	79.0	72.9	65.3
17	1430	300	21	80.9	73.5	68.5	41	1880	260	14	79.5	72.8	64.0
18	1710	390	22.5	83.5	76.2	69.3	42	1720	340	20	79.0	73.0	64.7
19	1650	360	22	80.7	74.1	65.0	43	1700	240	14	81.9	75.2	67.9
20	1610	240	15	82.2	73.5	64.6	44	1640	320	19.5	78.6	72.6	66.0
21	1850	290	15.5	82.0	75.6	68.0	45	1690	360	21	82.0	73.8	67.5
22	1800	300	16.5	81.2	75.5	68.0	46	1300	360	27.5	79.1	72.8	65.1
23	1380	180	13	81.0	73.1	63.8	47	1680	540	32	80.5	74.5	67.4
24	1780	440	24.5	84.3	75.5	66.6	48	1870	420	22.5	81.1	74.6	66.2

TABLE A2.1 (r)

10, EAST HEATH ROAD, N.W.3.

Gradient 10.9 % **Width** 6.6 m **Surface** Stoned asphalt

Location S.W. side, 50 m S.E. of corner of Heath Side, 1 km N.W. of Hampstead Heath Station.

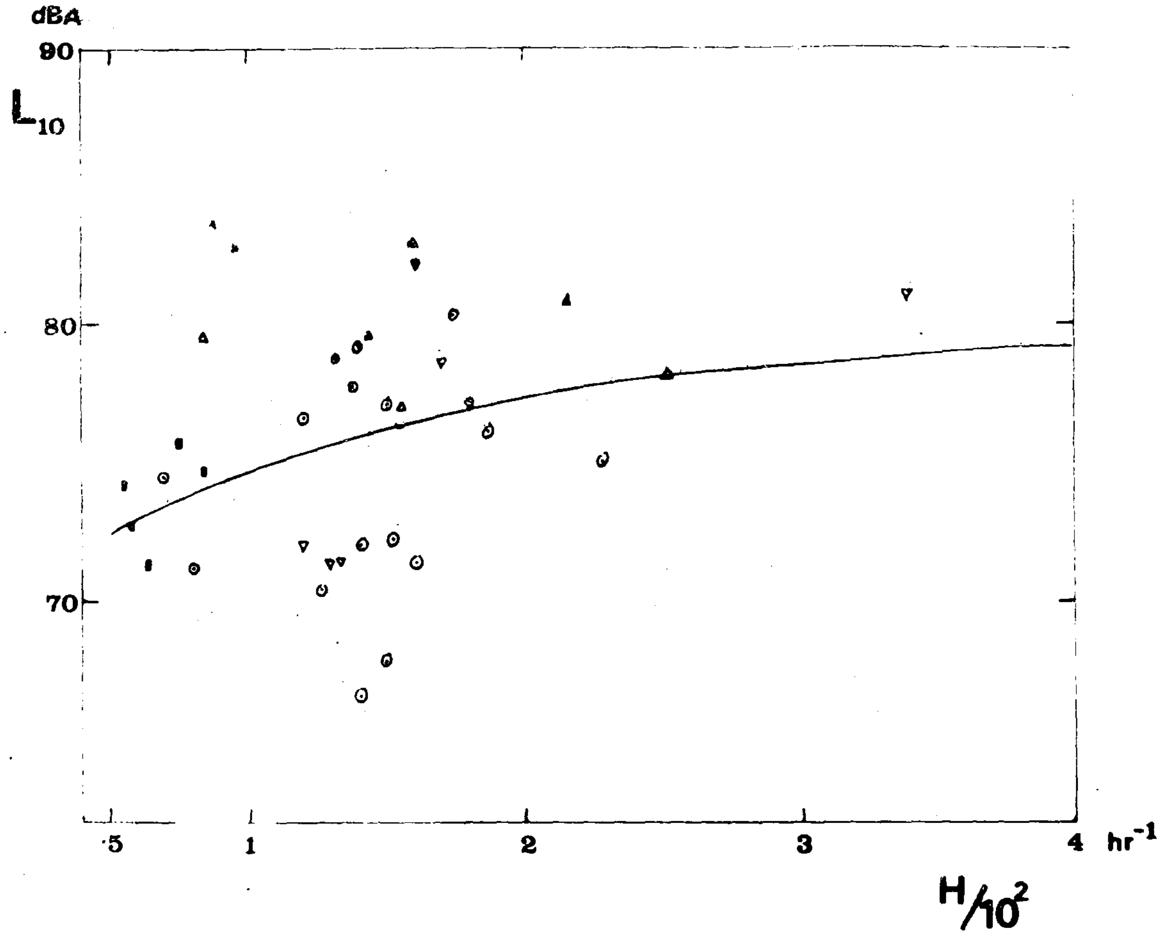
Characteristics Straight road with open spaces on both sides. Very open aspect.

Speeds Light vehicles: 40 to 50 km hr^{-1} in both directions
Heavy vehicles: 35 to 45 km hr^{-1} uphill, 40 to 50 km hr^{-1}, downhill

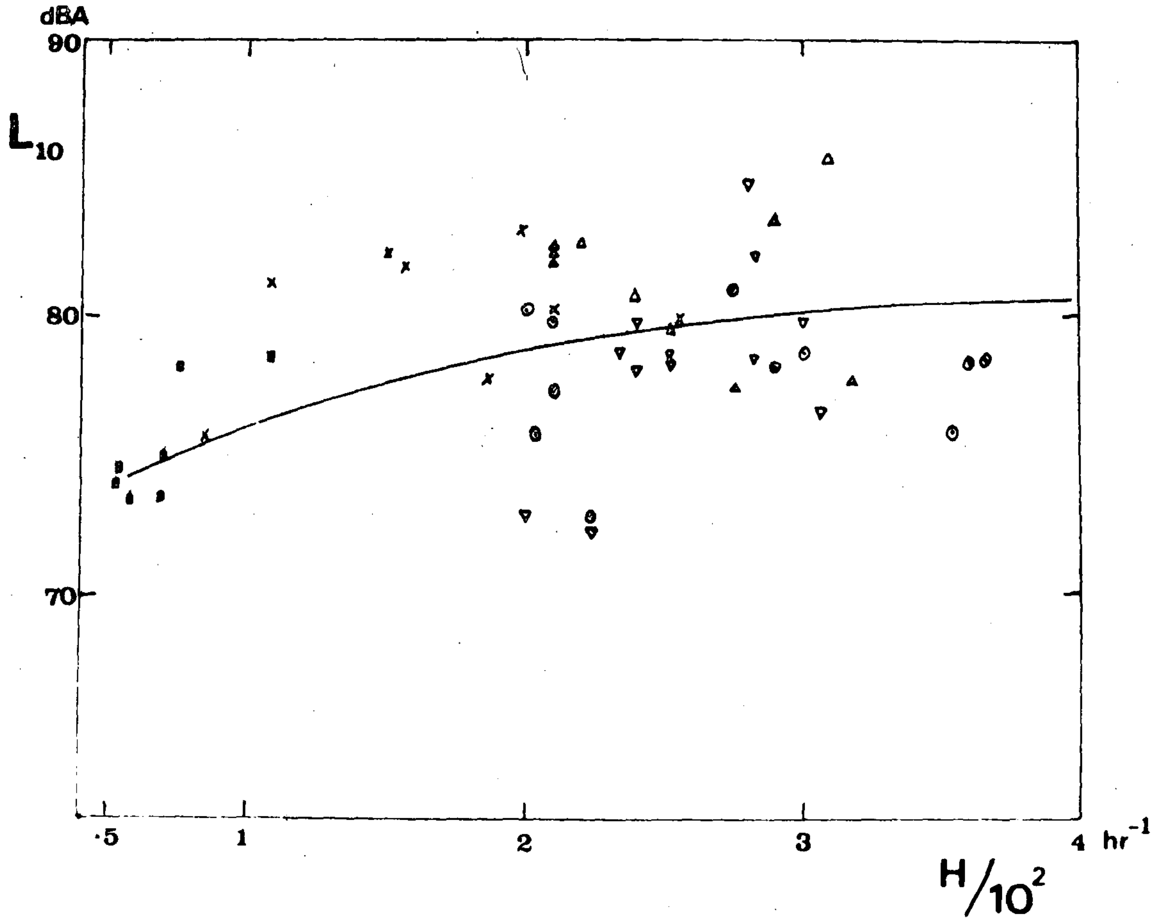
Remarks Steady flow; narrowness of road inhibits excessive speeding. Occasional bunching behind slow moving lorries.

Average proportion of heavy vehicles with 3 or more axles 5 per cent

TEST NUMBER	Q	H	$\frac{H}{Q}$	SOUND LEVELS		
				L_{10}	L_{50}	L_{90}
	hr^{-1}	hr^{-1}	%	dBA	dBA	dBA
1*	740	52	7	67.6	60.3	52.8
2*	920	44	5	67.8	61.3	54.9
3*	920	20	2	65.8	60.8	54.1
4*	1090	44	4	68.2	62.8	55.2
5*	1230	20	1.5	66.6	62.0	53.8
6*	1240	32	2.5	69.3	630	56.7
7*	700	60	8.5	669	60.0	53.2
8*	820	56	7	69.8	61.7	54.3
9	1030	120	11.5	67.7	62.2	58.8
10	820	100	12.5	69.4	66.4	62.0
11	700	54	7.5	68.3	62.1	61.2
12	640	66	10.5	68.5	62.1	58.4
13	730	78	10.5	66.5	61.3	59.2
14	740	130	17	69.7	61.9	58.6
15	57	6	10.5	64.7	59.0	57.3
16	220	19	8.5	65.8	59.0	56.9
17	650	24	3.5	69.5	63.5	59.5
18	1010	42	4	72.6	66.6	62.3
19	27	3	11	66.2	63.4	61.5
20	110	14	13	81.3	70.2	68.0
21	280	24	8.5	83.1	739	69.8
22	820	114	14	79.2	70.3	64.0
23	810	84	10.5	77.6	70.3	64.4
24	650	60	9.5	76.7	67.0	62.0
25	730	60	8	772	69.6	63.7
26	970	78	8	77.3	69.1	62.2
27	750	84	13.5	79.2	70.5	64.1
28	710	54	7.5	76.7	68.7	63.0
29	700	30	4.5	78.2	69.5	63.7
30	790	60	7.6	77.3	69.5	64.4
31	750	54	7	78.1	69.4	64.1
32	810	72	9	76.7	68.6	639
33	870	60	7	790	71.2	64.5
34	740	84	11.5	78.0	69.5	64.3
35	500	48	9.5	78.0	68.0	59.2
36	710	110	15	78.5	71.1	65.0
37	570	30	5	76.9	70.5	64.4
38	730	80	11	78.5	70.7	64.3
39	730	54	7.5	80.3	71.5	64.8
40	730	60	8.5	79.5	70.2	63.7
41	580	48	8.5	79.1	69.0	63.9
42	720	54	7.5	80.0	70.7	64.5
43	770	78	10	68.5	63.0	59.1
44	990	90	9	69.1	63.7	60.3
45	740	0	0	81.6	73.1	68.5
46	840	0	0	81.0	74.0	68.0
47	840	0	0	82.6	74.1	69.4
48	780	23	3	82.7	73.7	68.0
49	750	0	0	80.5	72.6	68.5



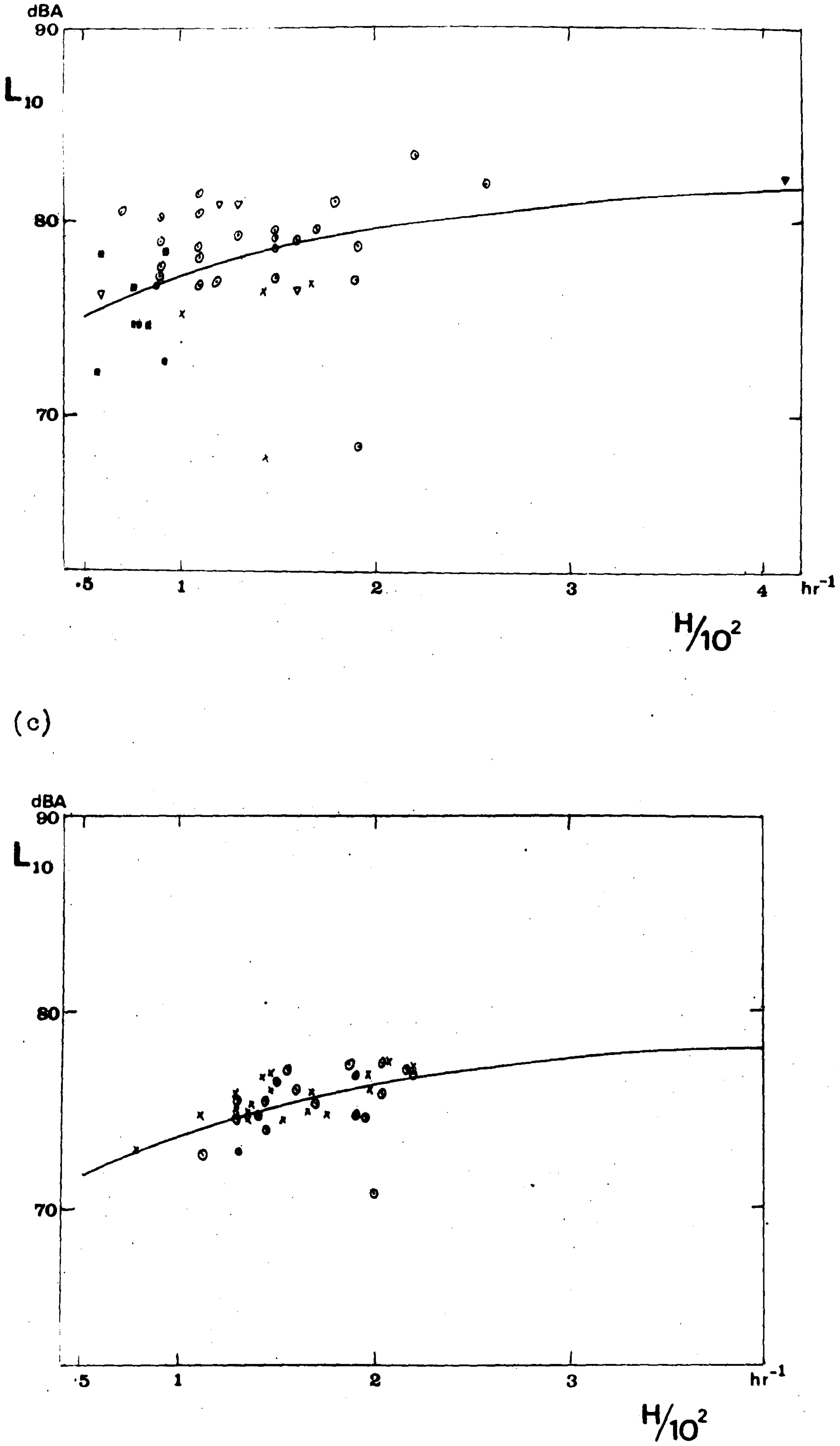
(a)



(b)

Figs. A2.1(a) and (b). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (a) Uxbridge Road (site 16), gradient 0.3 per cent, and (b) Shooters Hill Road (1) (site 26), gradient 0.4 per cent.

Values of Q, hr^{-1} ■ < 500, × 500 - 1000,



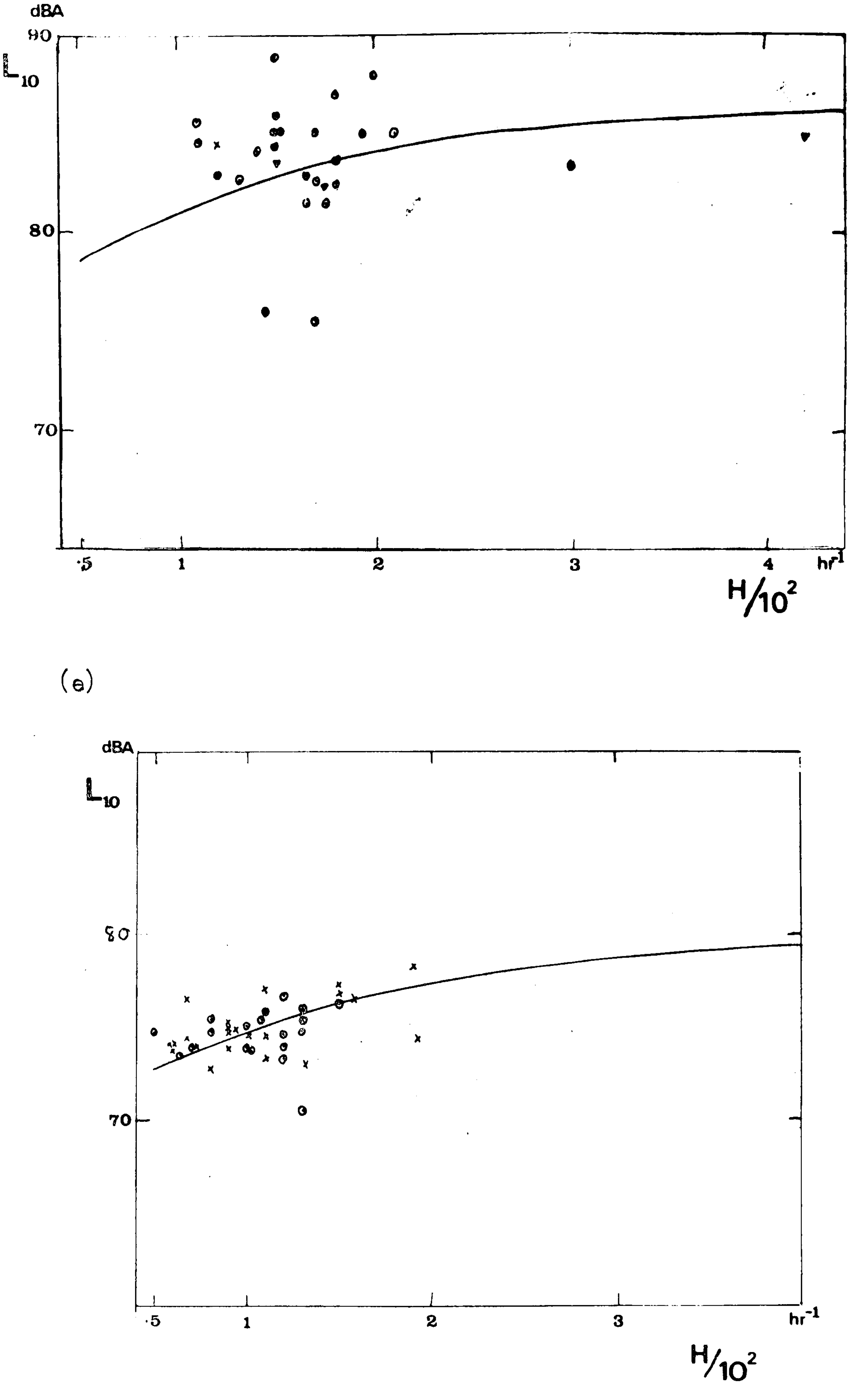
(c)

(d)

Figs. A2.1(c) and (d). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (c) Upper Ham Road (site 38), gradient 0.6 per cent, and (d) High Road, N. Finchley (site 22), gradient 1.5 per cent.

Values of Q, hr^{-1} ■ < 500 , × 500 - 1000

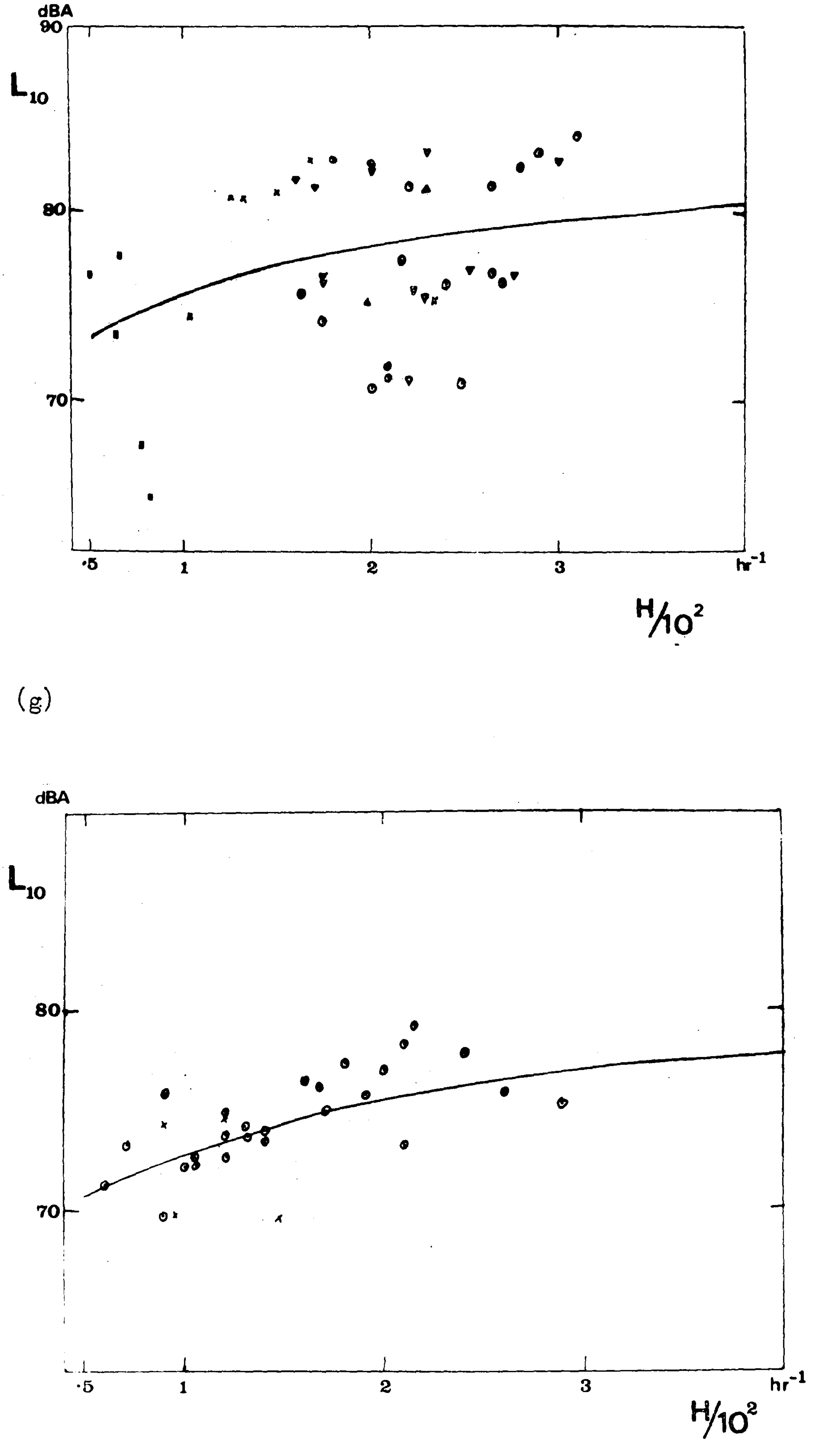
⊘ 1000 - 1500 , ▽ 1500 - 2000 , ▲ > 2000.



(f)

Figs. A2.1(e) and (f). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (e) Watford Road (site 1), gradient 2.3 per cent, and (f) Harrow Road (site 5), gradient 2.6 per cent.

Values of Q, hr^{-1} ● < 500, × 500 - 1000, ⊙ 1000 - 1500, ▽ 1500 - 2000, △ >2000.

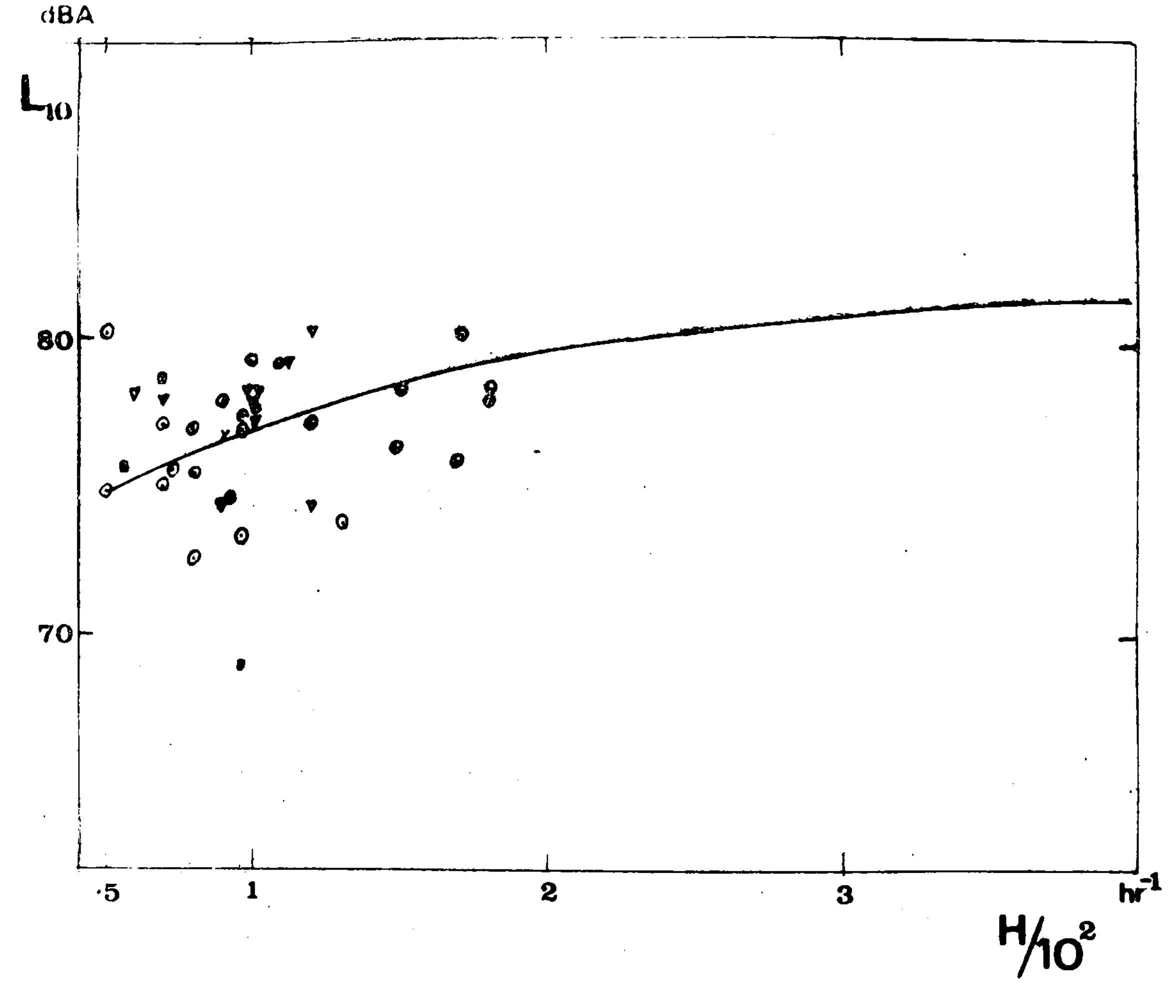


(g)

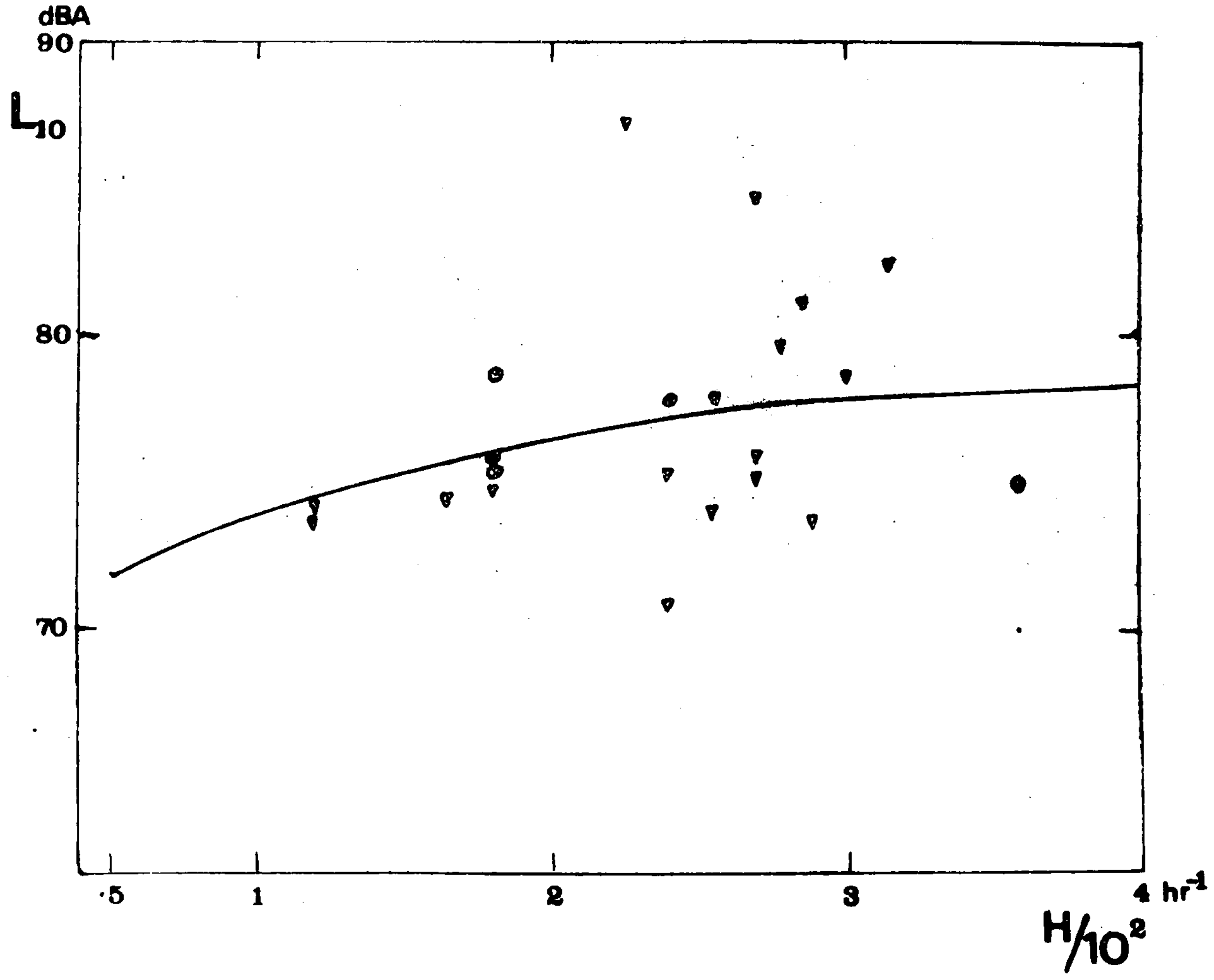
(h)

Fig. A2.1(g) and (h). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (g) Shoot-up Hill (site 7), gradient 2.8 per cent, and (h) Shooters Hill Road (2) (site 28), gradient 3.3 per cent.

Values of Q, hr^{-1} ■ < 500 , × 500 - 1000, ⊙ 1000 - 1500 ▽ 1500 - 2000, △ > 2000.



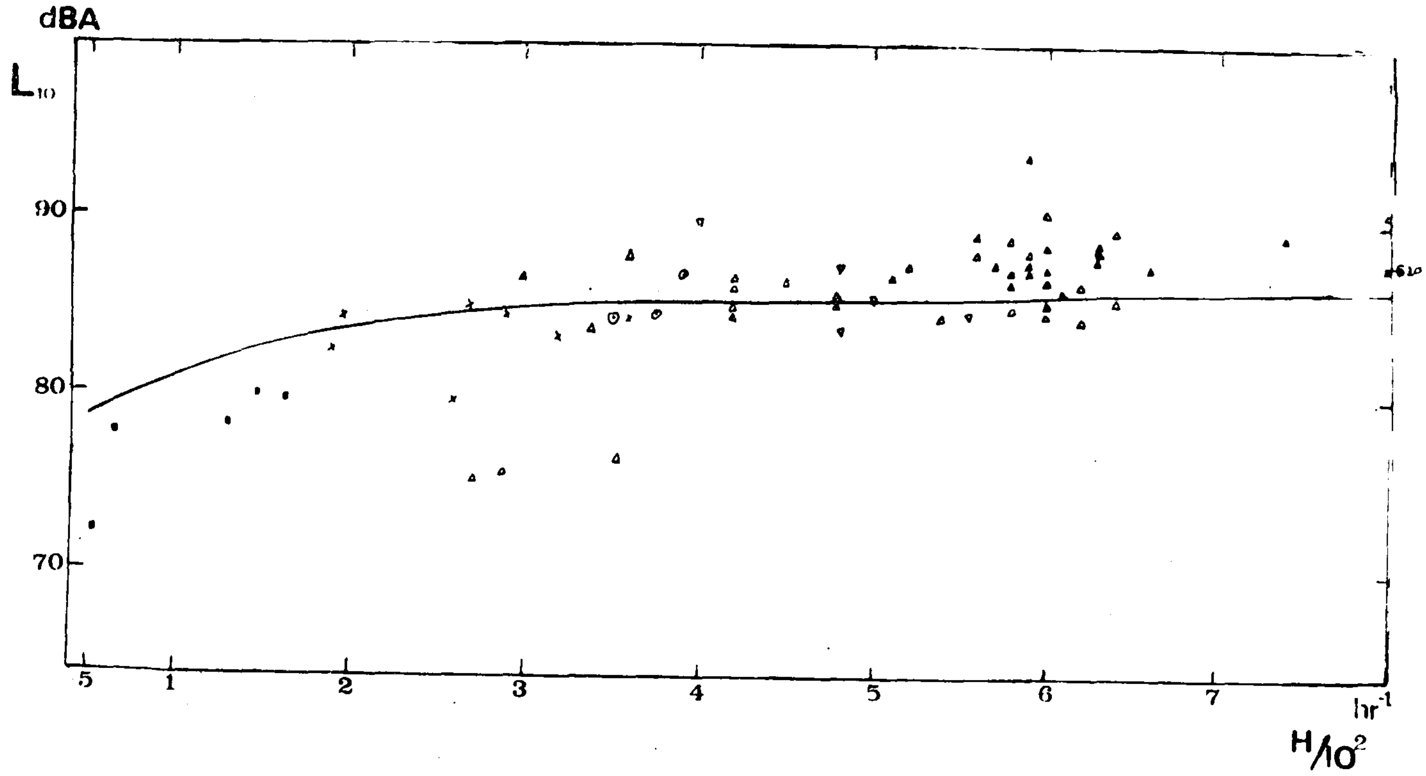
(i)



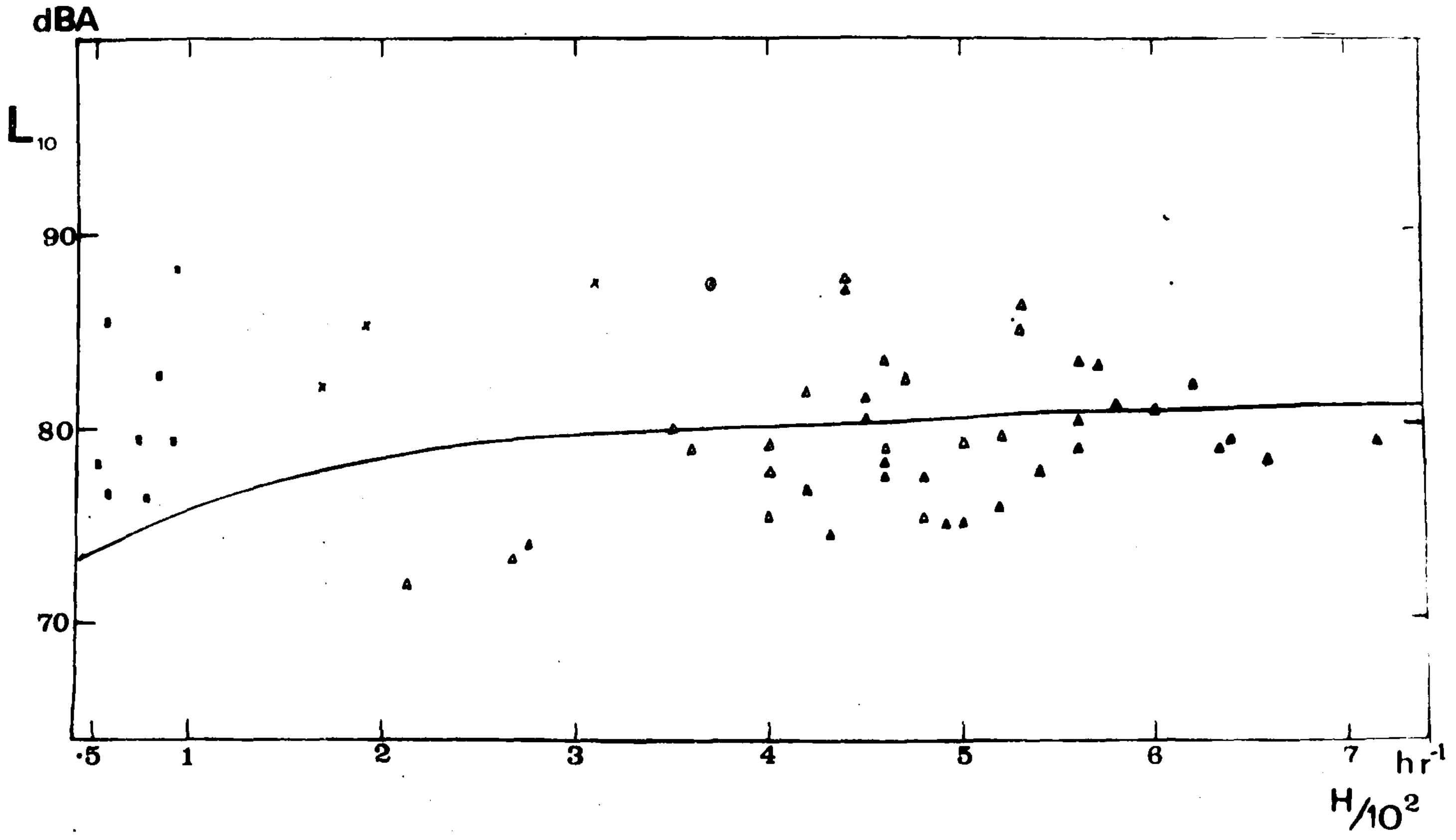
(j)

Fig. A2.1(i) and (j). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (i) Haverstock Hill (site 13), gradient 3.6 per cent, and (j) Balham Hill (site 47), gradient 4.3 per cent.

Values of Q, hr^{-1} ▪ < 500, ⅄ 500 - 1000,
1500 ▼ 1500 - 2000 ▲ > 2000.



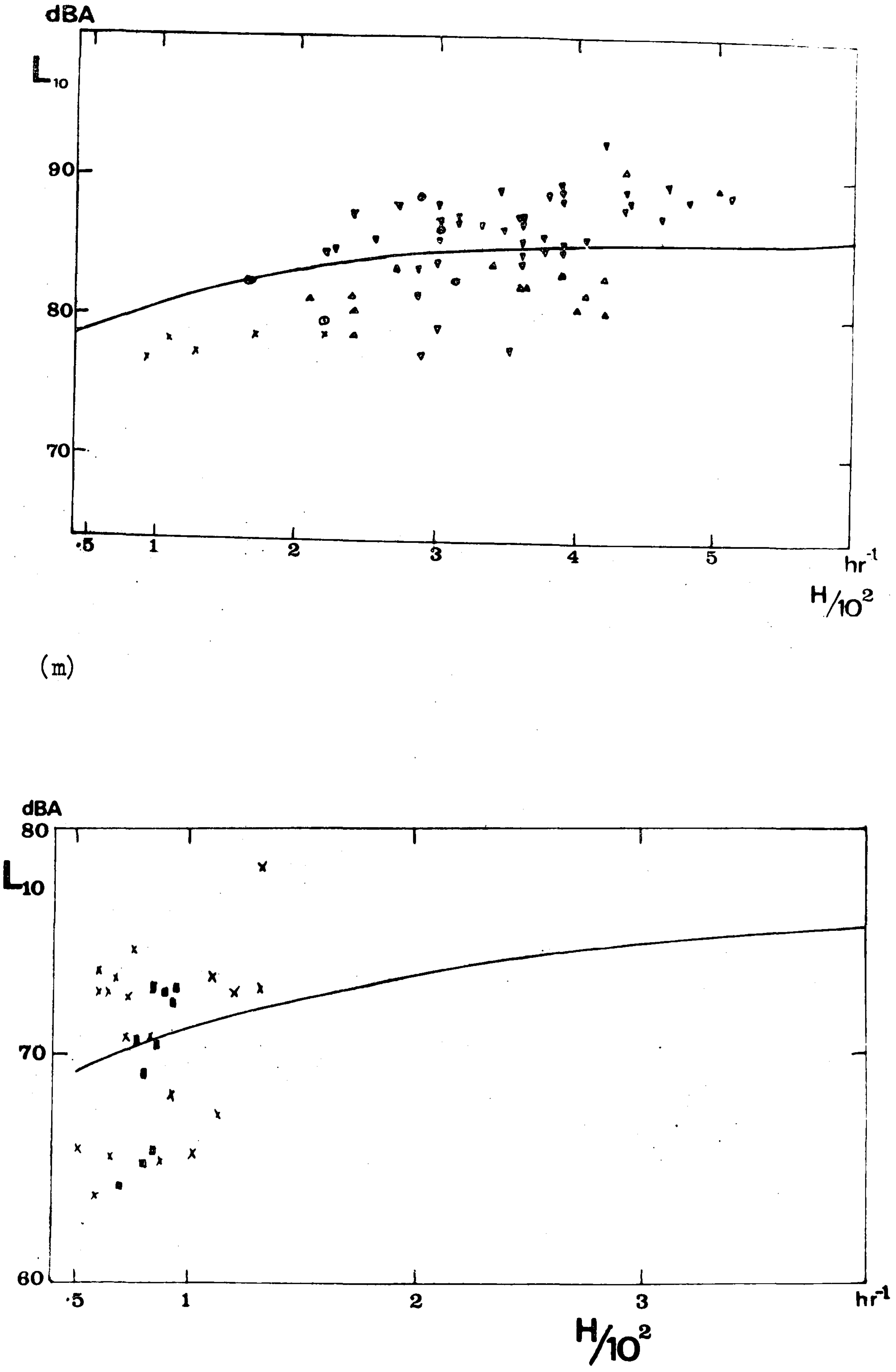
(k)



(l)

Fig. A2.1(k) and (l). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (k) N.Circular Road (site 20), gradient 5.0 per cent, and (l) Hanger Lane (site 15), gradient 6.3 per cent.

Values of Q, hr^{-1} ■ < 500 , ✶ 500 - 1000,
1500 ▼ 1500 2000 > 2000

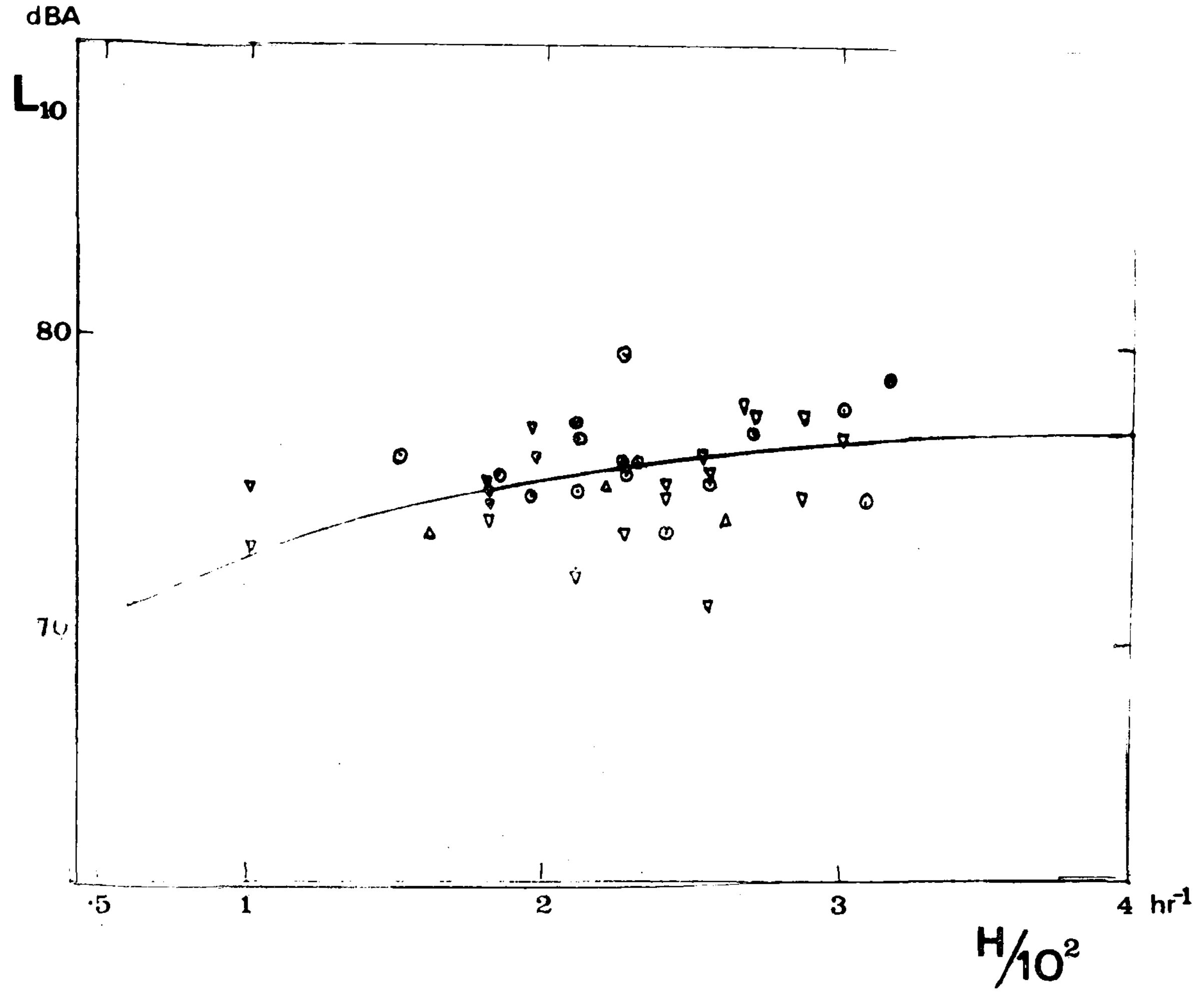


(m)

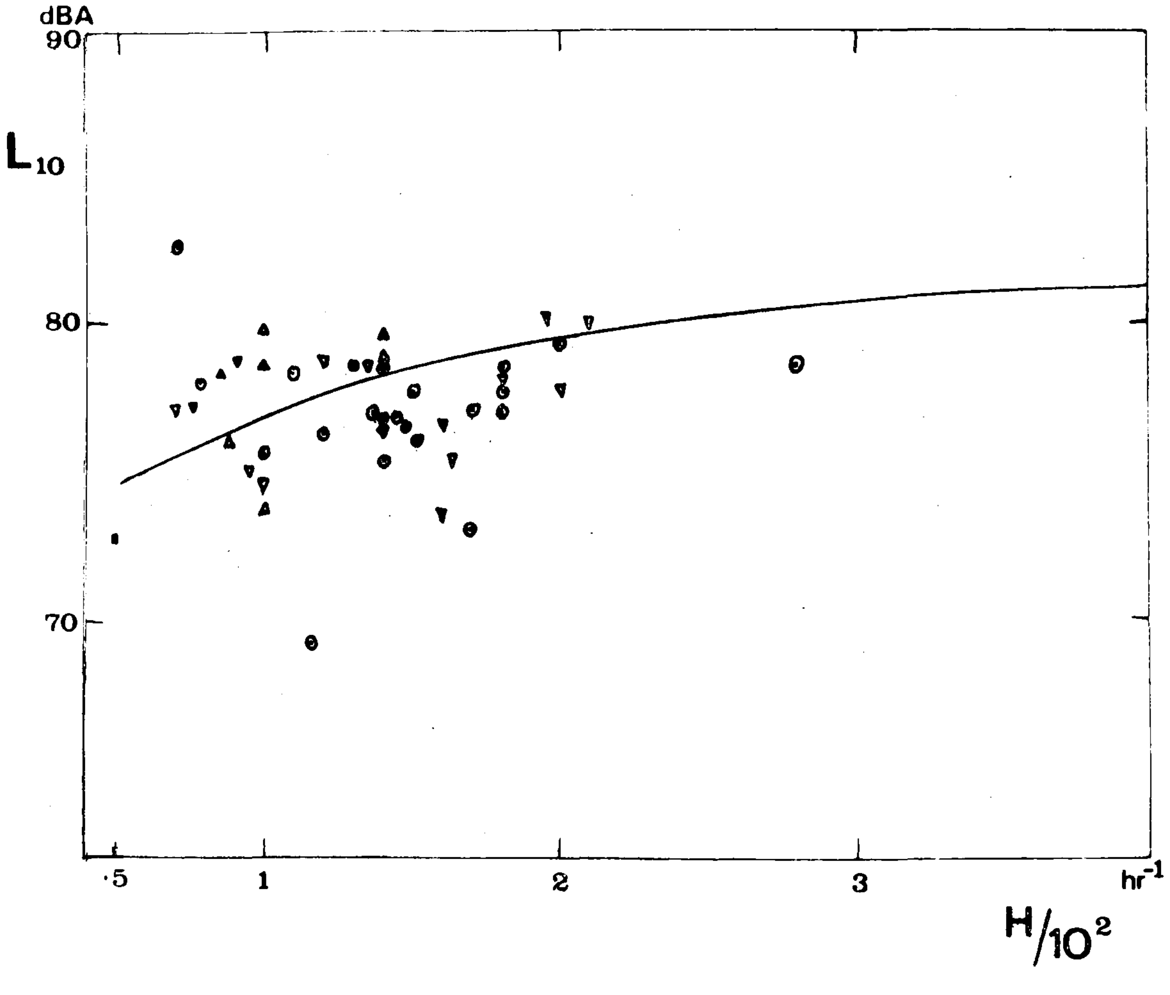
(n)

Fig. A2.1(m) and (n). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (m) Blackheath Hill (2) (site 27), gradient 7.6 per cent, and (n) Gore Hill, Amersham, (site 31), gradient 8.0 per cent.

Values of Q, hr^{-1} ■ < 500 , ✱ 500 - 1000



(o)



(p)

Fig. A2.1(o) and (p). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (o) London Road, S.E.23, (site 36), gradient 8.4 per cent, and (p) Muswell Hill (site 14), gradient 9.3 per cent.

Values of Q, hr^{-1} ● < 500, ✢ 500 - 1000, ⊙ 1000 - 1500, ▽ 1500 - 2000, △ > 2000.

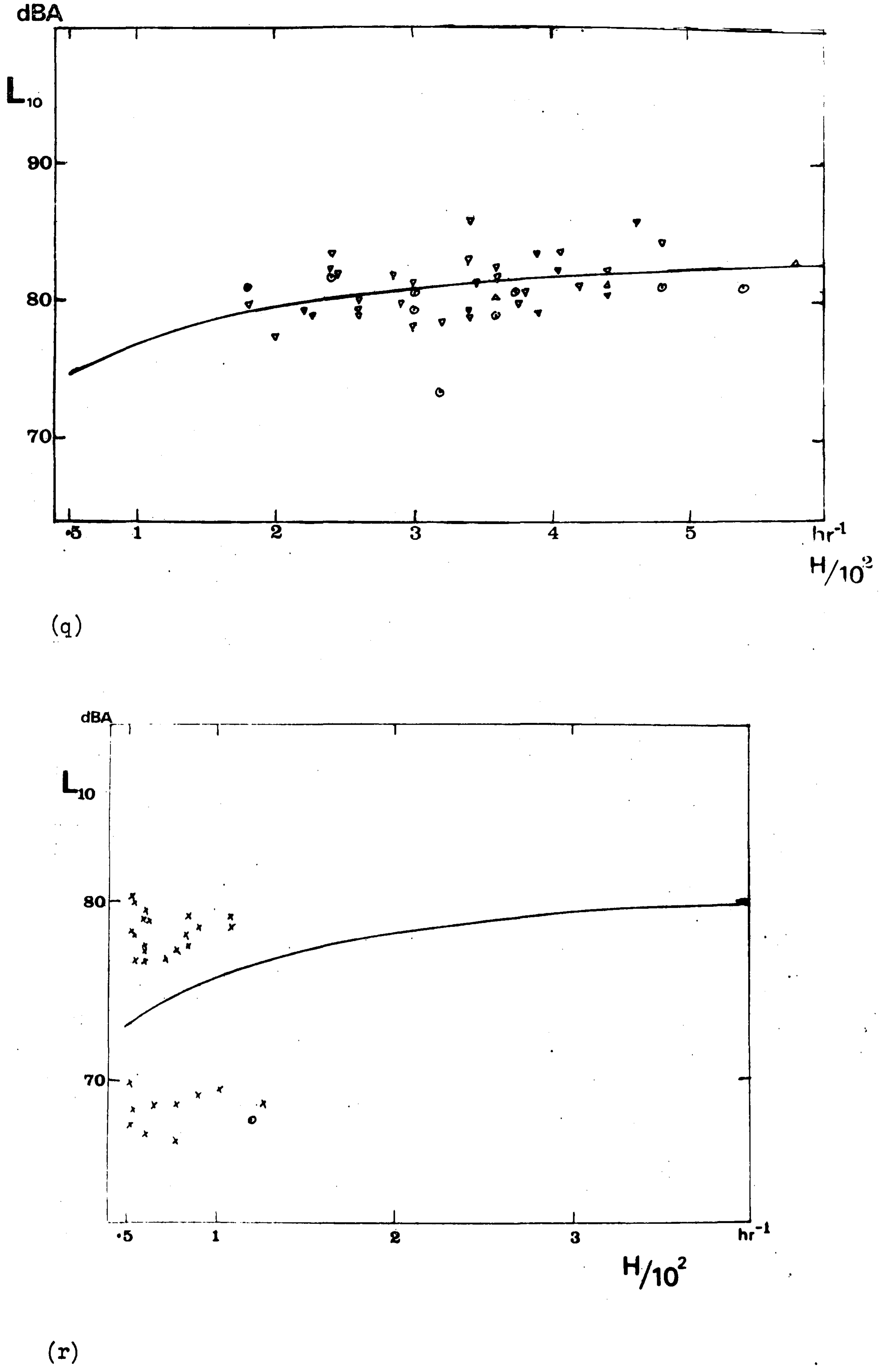


Fig. A2.1(q) and (r). Plot of L_{10} with rate of flow H of heavy traffic for the 10 m from the kerb position for (q) Blackheath Hill (1) (site 25), gradient 9.5 per cent, and (r) East Heath Road (site 10), gradient 10.9 per cent.

Q, hr^{-1} ● < 500, ✗ 500 - 1000,

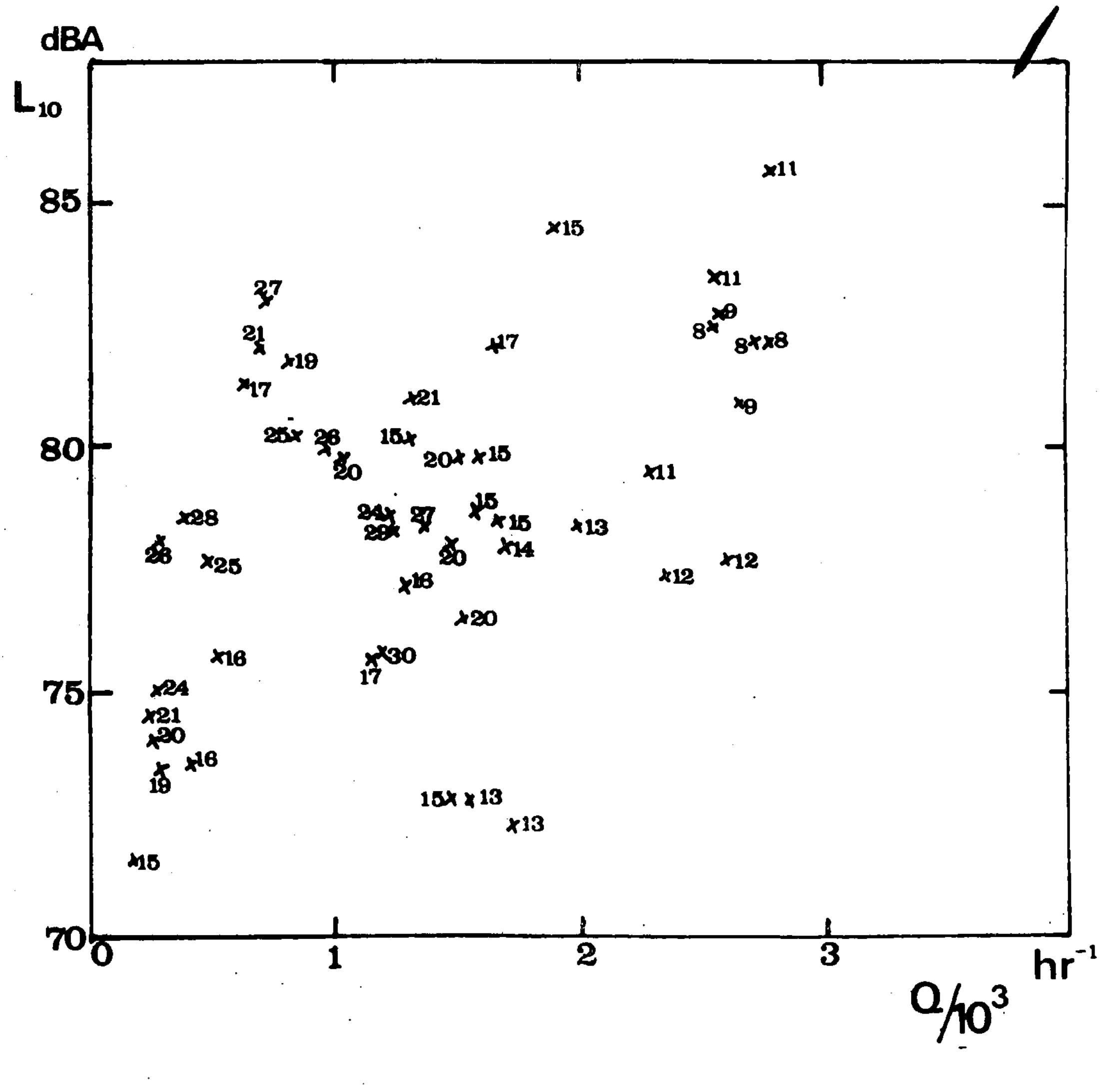


Fig. A2.2 Plot of L_{10} against total rate of flow Q of traffic for Shooters Hill Road (1) (site 26), gradient 0.4 per cent, for the 10 m from the kerb position. Figures ~~in brackets~~ denote percentages of heavy vehicles.

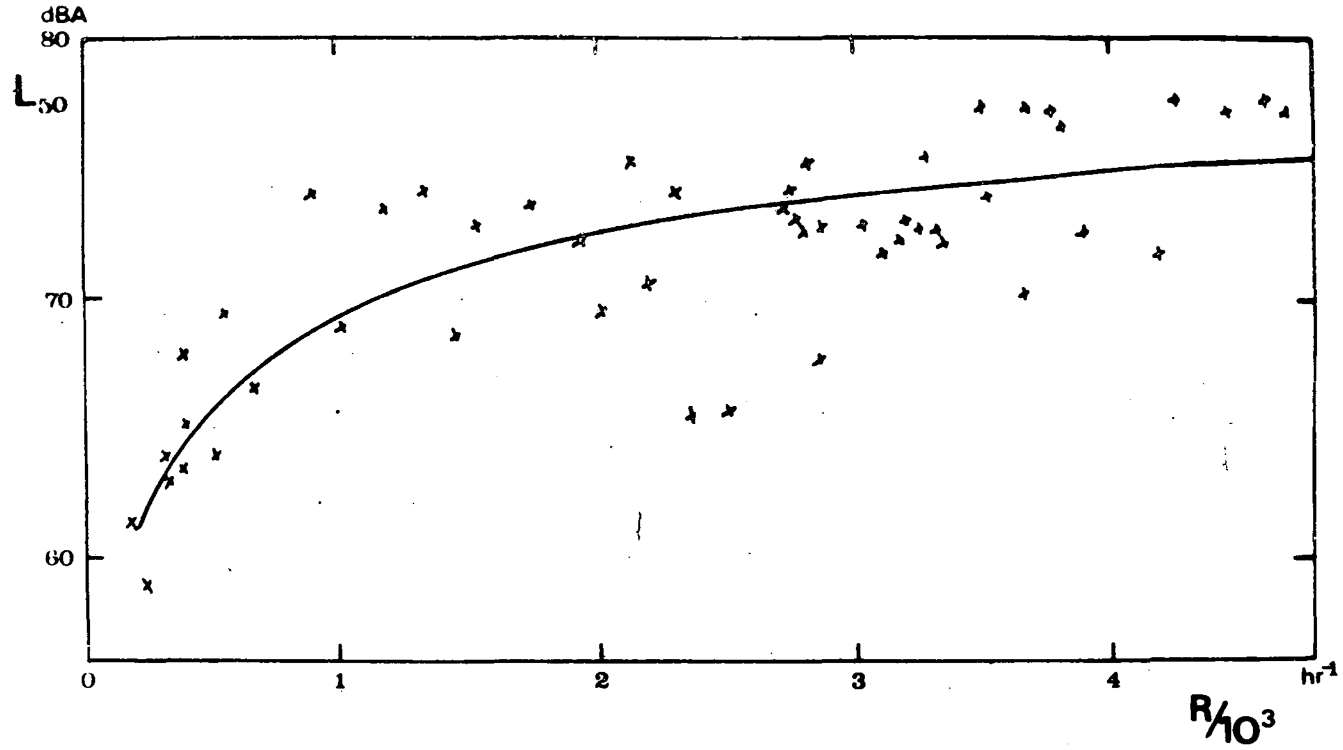


Fig. A2.3 Plot of L_{50} with the parameter $R = Q + H^2/50$ (see equation A3.9) for Shooters Hill Road (1) (site 26), gradient 0.4 per cent, for the 10 m from the kerb position.

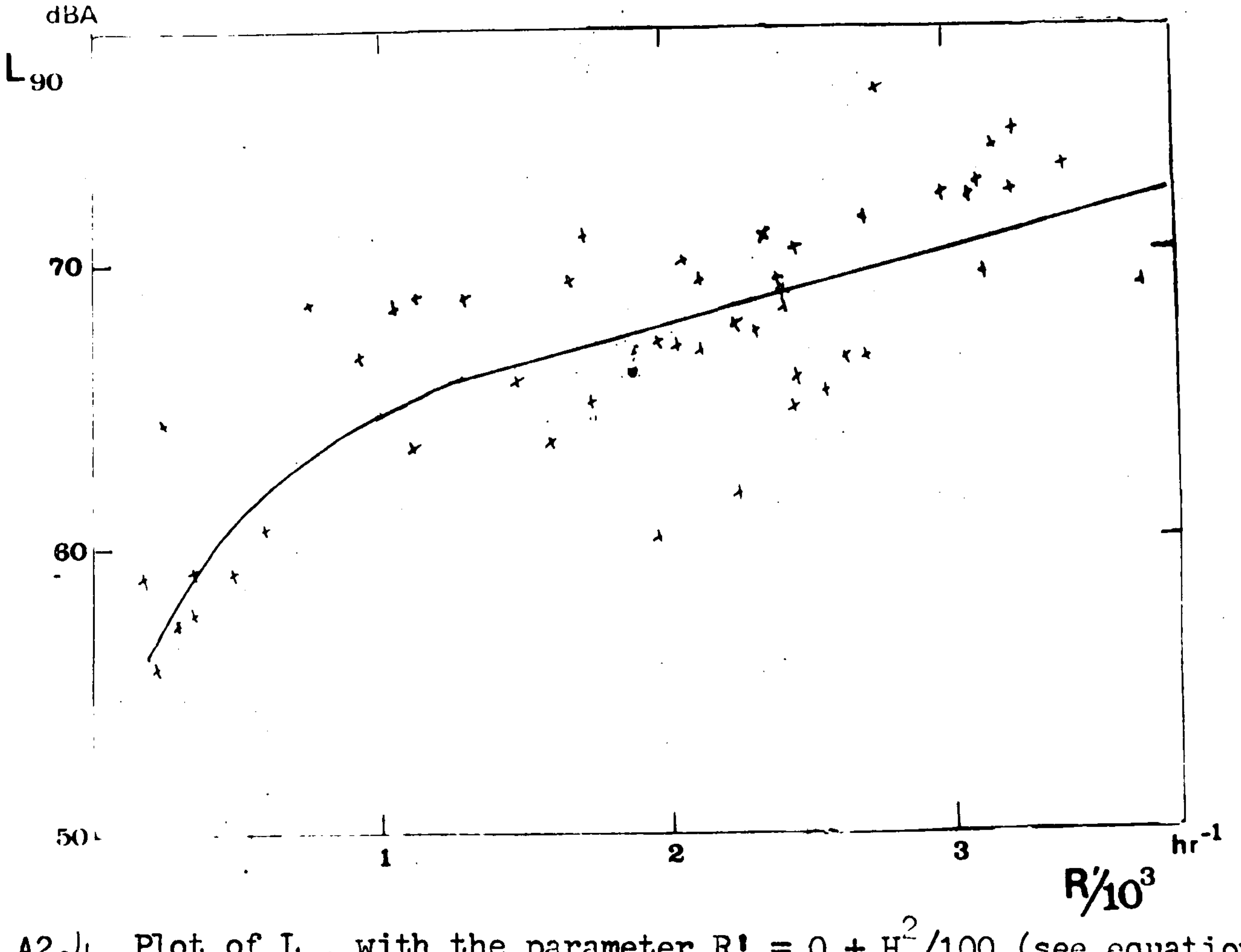


Fig. A2.4 Plot of L_{90} with the parameter $R' = Q + H^2/100$ (see equation A3.12) for Shooters Hill Road (1) (site 26), gradient 0.4 per cent, for the 10 m from the kerb position.

APPENDIX 3.

PARAMETERS FOR STUDYING VARIATIONS OF L_{50} AND L_{90} WITH RATES OF FLOW OF TRAFFIC.

A3.1 A PARAMETER FOR L_{50}.

In section 6.2 it is seen that the intensity I at a time t and a perpendicular distance d from the line of flow of traffic consisting of a single class of vehicle, of acoustic power P, is given by

$$I = Pk\frac{\pi}{sd}\left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - \cos(2\pi n v t/s)}\right] \qquad \text{A3.1}$$

where s is the distance of separation assumed to be constant, of neighbouring vehicles, v the steady speed and k a dimensionless constant. Putting $I_0 = Pk/d^2$, where I_0 is the reference intensity for the class of vehicle (i.e. the intensity when a single vehicle passes closest to the observer), we have

$$I = I_0 d^2\left(\frac{\pi}{sd}\right)\left[\frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - \cos(2\pi n v t/s)}\right] \qquad \text{A3.2}$$

The value I_{50} of the intensity exceeded for 50 per cent of the total time of observation is then given by:

$$I_{50} = I_0 d^2(\pi/sd)\tanh(2\pi d/s) \qquad \text{A3.3}$$

Putting Q = v/s, where Q is the rate of flow, this equation becomes

$$I_{50} = I_0 d^2 (Q\pi/dv) \tanh (2\pi d Q/v) \qquad \text{A3.4}$$

when $Q \gg v/d$, $\tanh\,(2\pi dQ/v) \rightarrow 1$ and

$$I_{50} \triangleq I_0 d^2 (Q\pi/dv) = I_0 (\pi d/v) Q \qquad \text{A3.5}$$

$d = 15$ m and $v = 45$ km hr^{-1}, this approximation is valid for a tolerance of 0.5 dBA when $Q \geqslant 750$ hr^{-1}.

Considering now heavy vehicles, we substitute Q for H. When $H \ll v/d$, $\tanh\,(2\pi dH/v) \rightarrow 2\pi dH/v$ and

$$I_{50} \triangleq I_0 (\pi d/v)(2\pi d H^2/v) \qquad \text{A3.6}$$

This equation is applicable when $H \leqslant 250$ hr^{-1}, again assuming a tolerance of ± 0.5 dBA.

Suppose, initially, that the stream of traffic consists entirely of light vehicles for which $Q \geqslant 750$ hr^{-1}. The value of I_{50} is then given by equation A3.5. If~~, in addition,~~ the traffic contains heavy vehicles with a rate of flow $H \leqslant 250$ hr^{-1}, for which the reference intensity is $10I_0$, replacing a similar number of light vehicles, we have effectively a total rate of flow Q having a reference intensity I_0 and an additional H vehicles per hour for which the reference intensity is $9I_0$ (see Fig. A3.1). Thus at a given time t, a number Ht of the total number Qt will have their intensities raised by $9I_0$. The total intensity exceeded for 50 per cent of the time is then given by

$$I_{50} = I_0 (\pi d/v)Q + 9I_0 (\pi d/v)(2\pi dH^2/v)$$

i.e. $$I_{50} = (\pi dI_0/v)(Q + 18\pi dH^2/v) \qquad \text{A3.7}$$

Substituting $d = 15$ m and $v = 45 \times 10^3$ m hr^{-1} gives

$$I_{50} = C(Q + H^2/50) \qquad \text{A3.8}$$

where C is a constant. The corresponding value of L_{50} is then given by

$$L_{50} = 10 \log_{10} (Q + H^2/50) + K \qquad \text{A3.9}$$

where K is a constant.

The above argument is not rigid because an assumption of equal spacing of vehicles is implied. Also it is not entirely true that the mean intensity, when considering two classes of vehicle flowing simultaneously, is equal to that exceeded for 50 per cent of the time. However, it does provide us with a useful parameter $R = Q + H^2/50$ with which the variation of L_{50} can be considered. This parameter is, strictly speaking, valid only when Q is greater than 750 hr^{-1} and H is less than 250 hr^{-1}. However, L_{50} appears to correlate well with values of R calculated from observed values of Q and H (see Section 9.3), even outside this range.

A3.2 A PARAMETER FOR L_{90}.

Considering again the flow of equally spaced vehicles at a steady speed we see from equation A3.2 that the minimum level of intensity I_{min} is given by

$$I_{min} = I_0 d^2 (\pi/sd) \tanh(\pi d/s) \qquad \text{A3.10}$$

The level L_{min} corresponding to the intensity I_{min} is unlikely, in most cases, to differ by more than a fraction of a dB from L_{90} (corresponding to I_{90}), the intensity exceeded for 90 per cent of the time (see Fig 6.2). Thus

$$I_{90} \bumpeq I_0 d^2 (\pi/sd) \tanh(\pi d/s) \qquad \text{A3.10(a)}$$

Working again to a tolerance of ± 0.5 dBA we have, for $v = 45 \times 10^3$ m s^{-1} and $d = 15$ m, that:

$\tanh\ (\pi dQ/v) \rightarrow 1$ when $Q \geqslant 1500$ hr^{-1} and
$\tanh\ (\pi dH/v) \rightarrow \pi dH/v$ when $H \lesssim 125$ hr^{-1}

Applying the same argument used in the previous section it is seen that

$$I_{90} \bumpeq C\,(Q + H^2/100) \qquad \text{A3.11}$$

i.e. $L_{90} \bumpeq 10 \log_{10} (Q + H^2/100) + K$ A3.12

where both C and K are constants.

Although the equation A3.12 is applicable only when $Q \geqslant 1500\ \mathrm{hr}^{-1}$ and $H \leqslant 125\ \mathrm{hr}^{-1}$, L_{90} appears to correlate fairly well with the parameter $R' = Q + H^2/100$ outside these limits. It may not be justified, however, in trying to reduce values of L_{90} to a given value of R' except when Q and H obey the above conditions.

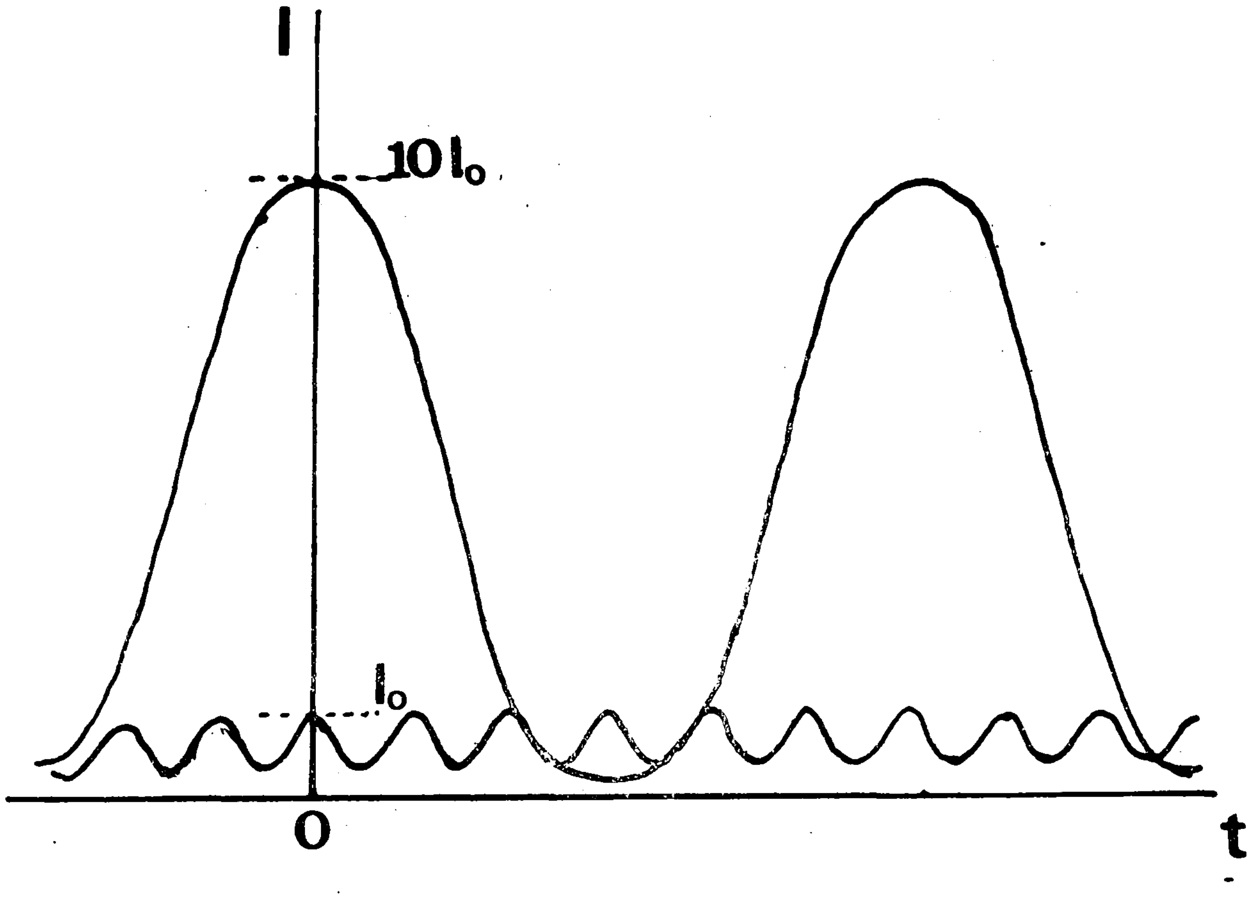


Fig. A3.1 Variation of intensity I with time t for a given rate of flow of vehicles having reference intensity I_0, and containing a proportion of vehicles having a reference intensity $10I_0$.