Noise Pollution
Edited by A. Lara Sáenz and R. W. B. Stephens

CHAPTER 12

Road Traffic Noise: Generation, Propagation and Control

C. Lamure

12.1 ROAD VEHICLES AS SOURCES OF NOISE

12.1.1 Sources of noise on the vehicles

The noise radiating from a motor vehicle can come from a number of different sources whose contribution to the total noise can depend on the speed of the vehicle. (see Figure 12.1). Table 12.1 shows the average, or rather the range of values, for the contribution to the total noise of the vehicle for each of these sources for both cars and heavy lorries. The amount of noise coming from each source depends very much on the type of vehicle involved and on the condition of the silencers. The noise due to the contact between the tyres and the road surface becomes dominant at high speeds. There are considerable variations in the relative contributions of noise coming from the engines and the exhaust systems in the case of two-wheeled vehicles.

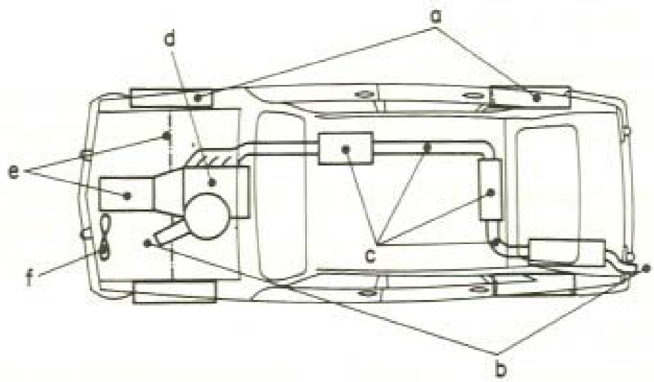


Figure 12.1 Sources of noise on a motor vehicle

Table 12.1 Percentage contributions from the different basic sources to the total amount of noise radiated by a well maintained road vehicle (IRT-CERNE, 1979)

Source of noise	Light vehicles		Heavy vehicles	
	Town	Open road	Town	Open road
Air intake inlet, exhaust outlet	15 to 35		15 to 60	
Exhaust pipe assembly	15 to 30	20 to 70		40 to 80
Engine block	20 to 30		30 to 80	
Gear box and transmission	5 to 30			
Cooling fan	–		10 to 50	
Tyre-road surface contact	5 to 10	30 to 80	5	20 to 60

A. *Engine noise*

The explosions inside the cylinders and the impact of the pistons against the cylinder walls excite the block and the various engine accessories, including in particular the different cases and housings. The latter include the sump case and the rocker arm cover, which often account for a significant proportion of the total noise coming from the engine.

The amount of noise radiated by the engine depends on its speed and the load to which it is being submitted, the latter determining the torque that is being produced.

The load does not have much effect in the case of a **diesel engine**, except for delayed indirect injection which can lead to a 5 dB reduction in the noise level when the engine is lightly loaded. For frequencies above about 500 Hz, the noise level L in dB(A) at a given frequency increases in proportion to 30 log N, i.e.

$$L_A = 30 \log N + \text{constant}$$

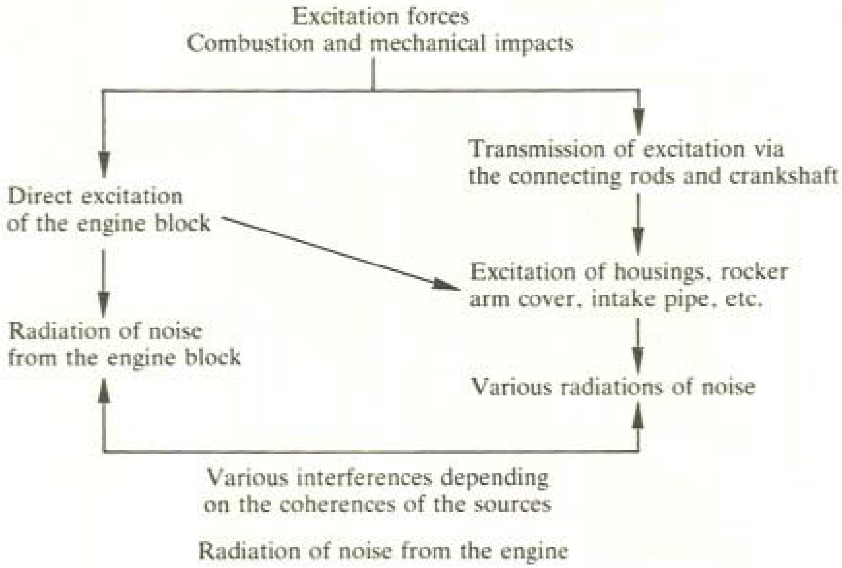
where N is the engine speed in r.p.m.

On examining the frequency spectrum for the noise it will be seen that the acoustic pressure level falls at a rate of 30 dB per decade for frequencies above 2000 Hz.

In the case of **spark ignition engines** the effect of load can account for as much as 5 to 6 dB(A) in the level of noise and it is found that the acoustic pressure level increases very rapidly with engine speed in accordance with the relationship:

$$L = 50 \log N + \text{constant}$$

The acoustic pressure level in the case of these engines falls at the rate of 50 dB per decade above a frequency of 2000 Hz.



The noise level does not increase so rapidly with the engine capacity C and we can say that in principle the total noise level in dB(A) varies as follows:

Diesel engines:	$L_A = 30 \log N + 17.5 \log C$
Supercharged diesel engines:	$L_A = 40 \log N + 17.5 \log C$
Spark ignition engines:	$L_A = 50 \log N + 17.5 \log C$

These equations show that for the same power output a large capacity engine, which will be running at a lower speed, will be quieter than a faster running engine. The following graph (Figure 12.2) shows how the noise level for different types of engine varies with engine speed and rating.

B. Noise coming from the transmission and silencers

We do not have a very good understanding of the noise coming from the gear box and the transmission and it is considered that the mechanical excitation here can be partially due to the engine. It is known moreover that on certain cars the noise coming from the complete transmission system can be dominant. The most simple sound-proofing measure than can be applied in connection with this noise is the provision of a screen beneath the complete transmission system, which can usually take the form of a simple extension of the screen fitted beneath the engine.

The reduction of noise as a result of the provision of silencers associated with

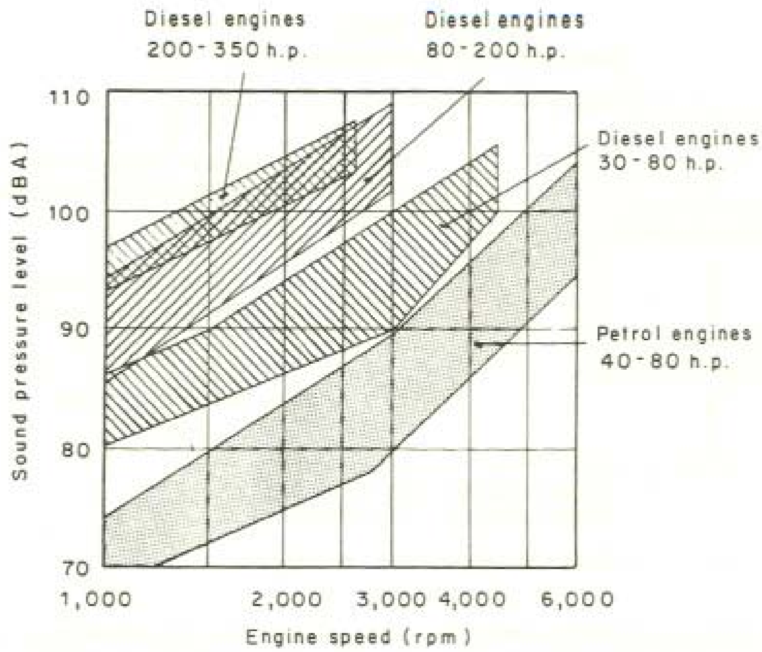


Figure 12.2 Noise level as a function of steady engine speed for different types of engine (Priede, 1971)

the air intake and engine exhaust systems gives rise above all to problems in connection with the life and size of these accessories. The size of the silencers is a problem in that their effectivness at low frequencies is a function of their volume.

C. *Noise due to the tyre-road surface contact*

The rolling noise is due to a number of different effects as is shown in Table 12.2. So far as the generation of noise is concerned we can classify the surface texture of the road surface in terms of the power spectral density of the longitudinal profile for wavelengths ranging from 2 to 200 mm (Sandberg and Descornet, 1980). If we define the mean square of the surface irregularities over a range of wavelengths centred on λ as T_λ, then the 'texture factor' can be expressed as:

$$L_\lambda = 10 \log_{10} \frac{T_\lambda}{10^{-12}}$$

where L_λ is expressed in dB with reference to a level of 10^{-12} m^2.

Surfaces having a high 'texture level' give rise in particular to radial excitation of the tyre and type I phenomena predominate. Surfaces having a low 'texture level' on the other hand give rise in particular to type II and type III disturbances.

Table 12.2 Noise due to tyre–road contact

	Phenomenon	Road surface parameter
I	Vertical excitation and radiation of noise from the tyre casing	Longitudinal profile (macrotexture) Mechanical impedance at the point of contact (elastic properties of the road)
II	Tangential excitation as a result of stick and slip action	Physico-chemical properties and longitudinal profile
III	Suction and expulsion of air (air pumping and air pocket resonance)	Geometry and porosity
IV	Aerodynamic action and air turbulence	None
V	Radiation of noise from the road itself	Elastic properties of the different layers making up the road structure
VI	Radiation of noise from the vehicle body or the load being carried	Profile (surface evenness)

Figure 12.3 shows the texture level and the noise frequency spectra for two different road surfaces, namely a rough surface made up of a double bituminous coating and giving rise to a high level of noise at the lower frequencies, and a surface consisting of a non-macadam blinded and closed asphaltic concrete giving rise to noise where frequencies above 1000 Hz predominate. The vehicle speed involved here amounted to 80 km/hour.

The importance of the impedance of the road surface is also not very well understood. All that is known is that road surfaces having a high mechanical impedance (hydraulic concrete or an old bituminous surface) tend to give rise to a greater degree of noise than road surfaces of moderate impedance such as recently layed bituminous surfaces, although the difference in noise level is not very great, amounting in fact to only a few decibels.

Experimental results. The results of some early work suggested that there was some relation between the skid resistance of a road surface and the generation of noise. However, as a result of work carried out since 1979 it is now known that this relation is only true on being considered for each particular type of road surface. Thus there is no basic relation between the average depth of the road surface texture, as determined on carrying out a sand test, and the generation of noise.*

* This test is a matter of packing a small area of the road surface with sand and smoothing off the surplus so as to determine the average depth of the surface texture.

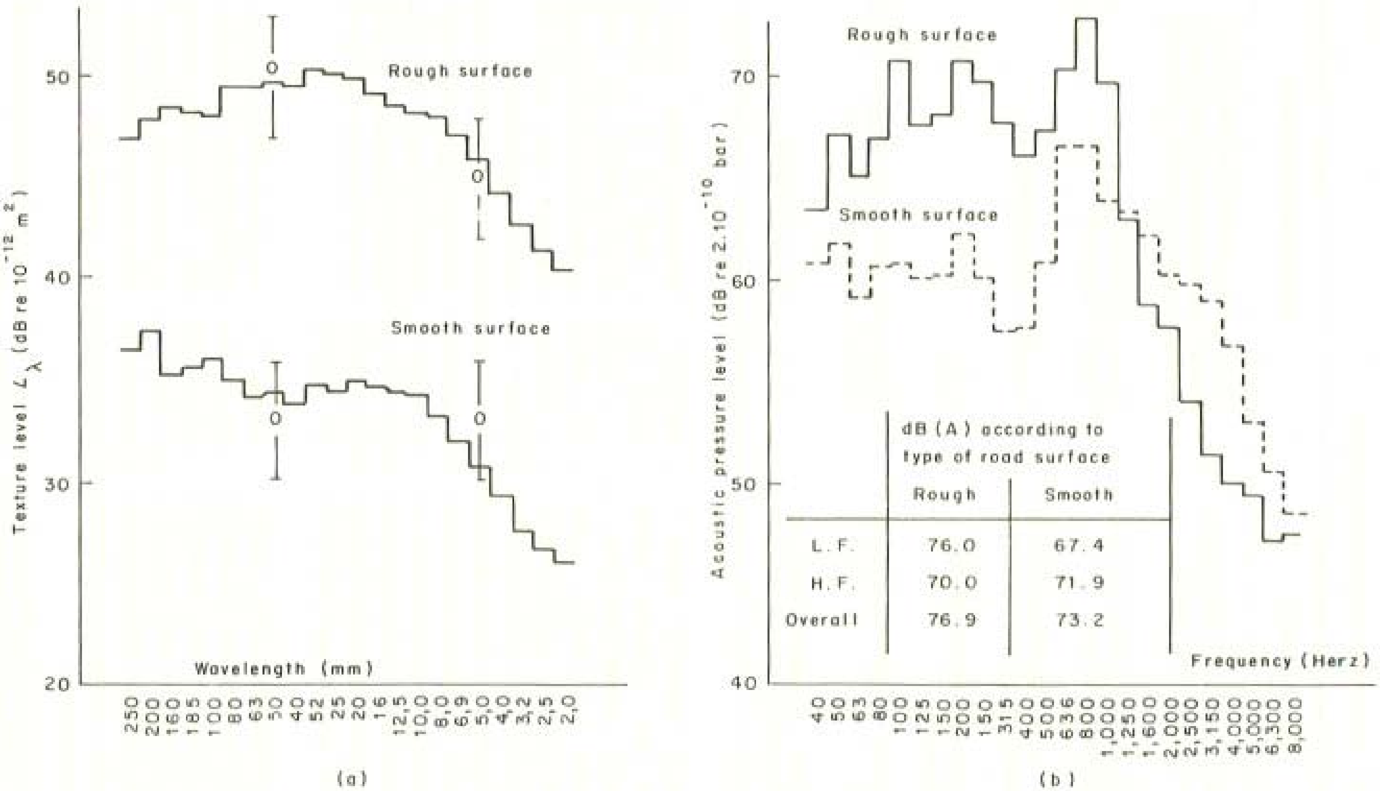

Rough surface
Smooth surface
Texture level L_λ (dB re 10^{-12} m^2)
50
40
30
20
Wavelength (mm)
250 200 160 185 100 80 63 50 40 52 25 20 16 12,5 10,0 8,0 6,9 5,0 4,0 3,2 2,5 2,0
(a)
Rough surface
Smooth surface
Acoustic pressure level (dB re 2.10^{-10} bar)
70
60
50
40
dB (A) according to type of road surface
Rough
Smooth
L.F. 76.0 67.4
H.F. 70.0 71.9
Overall 76.9 73.2
Frequency (Herz)
40 50 63 80 100 125 150 200 150 315 400 500 636 800 1,000 1,250 1,600 2,000 2,500 3,150 4,000 5,000 6,300 8,000
(b)

Figure 12.3

On making use of laser beams it is now possible to determine the power spectral densities of road surface profiles with a high degree of accuracy and at low cost.

Rolling noise increases very rapidly with vehicle speed V because the overall acoustic power that is generated increases in proportion to the third to fourth power of V. Thus we have:

$$L_{RA} = 30 \text{ to } 40 \log V + \text{constant} \qquad \text{(see Figure 12.4)}$$

Thus the noise level increases by more than 6 dB(A) when the speed is multiplied by a factor of 1.5. Figure 12.4 shows how the noise varies with speed for different types of tyre fitted to cars and heavy lorries. The noise level for the same road surface can differ by nearly 8 dB in the case of cars and by more than 12 dB in the case of heavy lorries.

Finally it should be noted that there are indications that it will be possible in future to provide new and quieter road surfaces for highway sections where high road surfacing costs would be acceptable in comparison with the cost of reducing noise by other means.

12.1.2 Noise from the Vehicle as a Whole

A. Noise as a Function of Engine and Road Speeds

The above considerations have shown how the total noise emitted by a vehicle is the sum of the noise coming from different sources where the contribution from each source depends on the engine speed N except for the rolling noise which depends on the road speed V. The relation between V and N is determined by the gear ratio that is in operation and in the case of a four-speed gearbox, the variation of the noise level with road speed for different gear ratios tends to be as shown by the graph of the following Figure 12.5.

The overall effect of acceleration, also shown on this graph, is not very great except when starting from rest and when re-engaging first and second gear. When running in fourth gear, the noise is mainly due to the tyre-road surface contact.

In the case of heavy lorries, the gearbox allows any one of a number of different gear ratios to be selected so as to ensure that the engine operates over the range resulting in minimum fuel consumption. The level of noise in this case is not very dependent on the gear ratio that is being employed.

B. Noise Frequency Spectra

There is a very rapid attenuation of the noise from cars, heavy lorries and two-wheeled vehicles for frequencies above 2,000 Herz and rolling noise becomes significant over the octave from 1,000 to 2,000 Herz. The acoustic

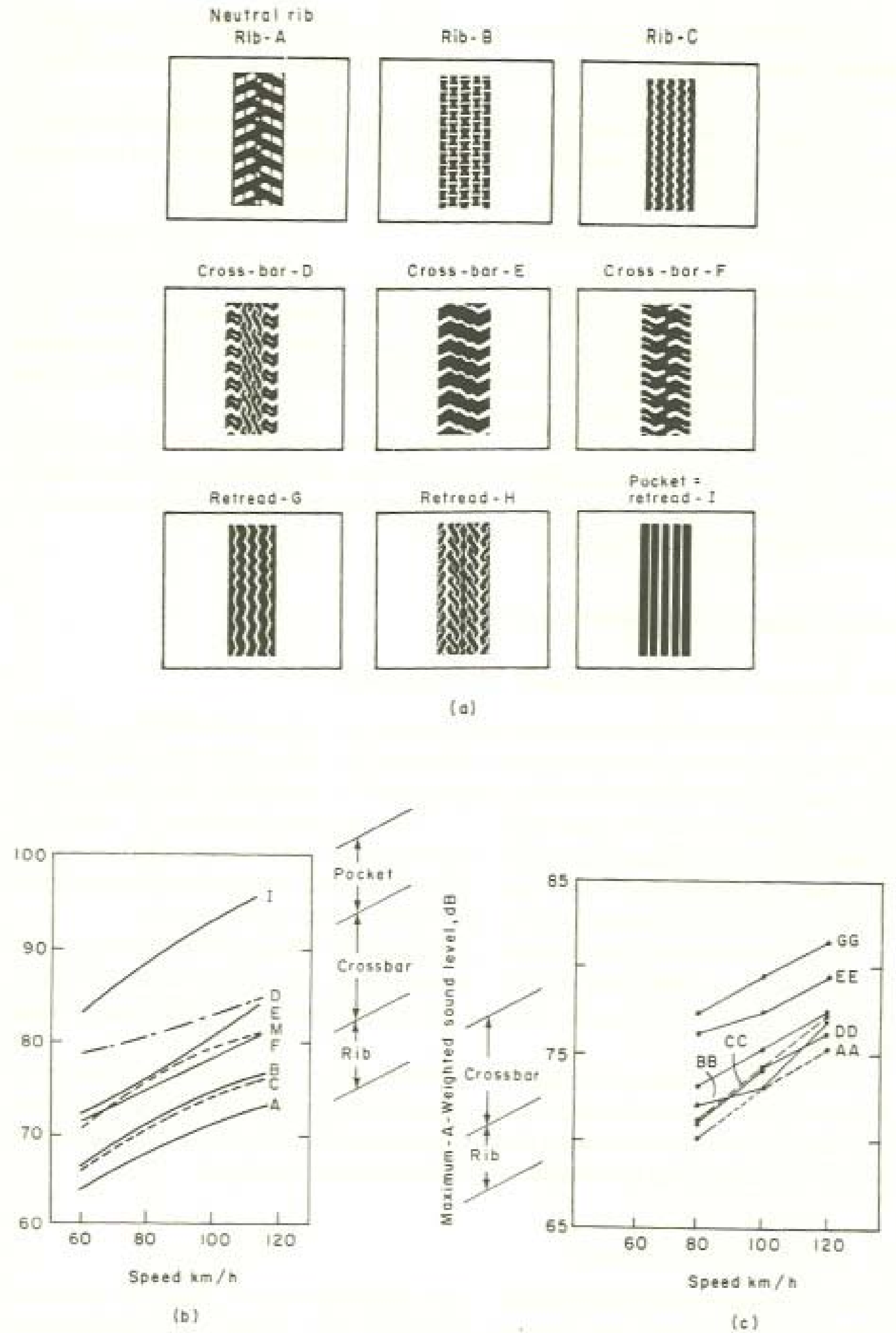

Neutral rib
Rib-A
Rib-B
Rib-C
Cross-bar-D
Cross-bar-E
Cross-bar-F
Retread-G
Retread-H
Pocket =
retread-I
(a)
100
90
80
70
60
I
D
E
M
F
B
C
A
60
80
100
120
Speed km/h
(b)
Pocket
Crossbar
Rib
Maximum-A-Weighted sound level, dB
Crossbar
Rib
85
75
65
GG
EE
DD
AA
CC
BB
60
80
100
120
Speed km/h
(c)

Figure 12.4

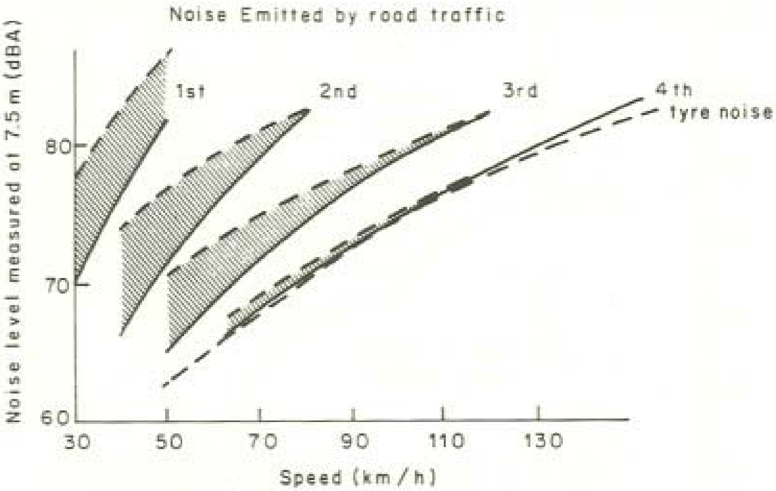


Figure 12.5 Noise from a Renault R16 car for different speeds and accelerations when running in first, second, third and fourth gear

pressure for heavy lorry engines rises to a very high level at the lower frequencies. The graph of Figure 12.6 shows the frequency spectra for isolated vehicles and the standard frequency spectrum that is taken into account when studying the sound proofing of building facades. The A-weighted spectrum shows that in the case of a zone located at a distance of 50 metres from the road, the perceived traffic noise is mainly confined to the three octaves ranging from 250 to 2,000 Herz.

12.1.3 Acoustic Power and Pressure and Evaluation of L_{eq} for an Isolated Vehicle

A. Acoustic Power and Pressure

For a point source of noise in free space radiating in all directions and

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Figure 12.4 Tyre-road contact noise in dB(A) at a distance of 7.5 m for different types of tyres on a concrete surface (National Bureau of Standards, 1970)(Leasure & Bender, 1975)

(a) Different types of truck tyre tread design (U.S.)

(b) Maximum A-weighted sound level (in decibels *re* 20 μPa) is measured at 50 ft, versus speed for a loaded single-chassis vehicle running on a concrete surface. Various types of new tyres were mounted in dual pairs on the drive axle. Letter designations for each curve correspond to the tyre types

(c) Maximum A-weighted sound level (in decibels *re* 20 μPa), as measured at 50 ft, versus speed for a full-size passenger automobile running on a concrete surface. Various types of new tyres were mounted on the rear axle. Letter designations for each curve correspond to the tyre types

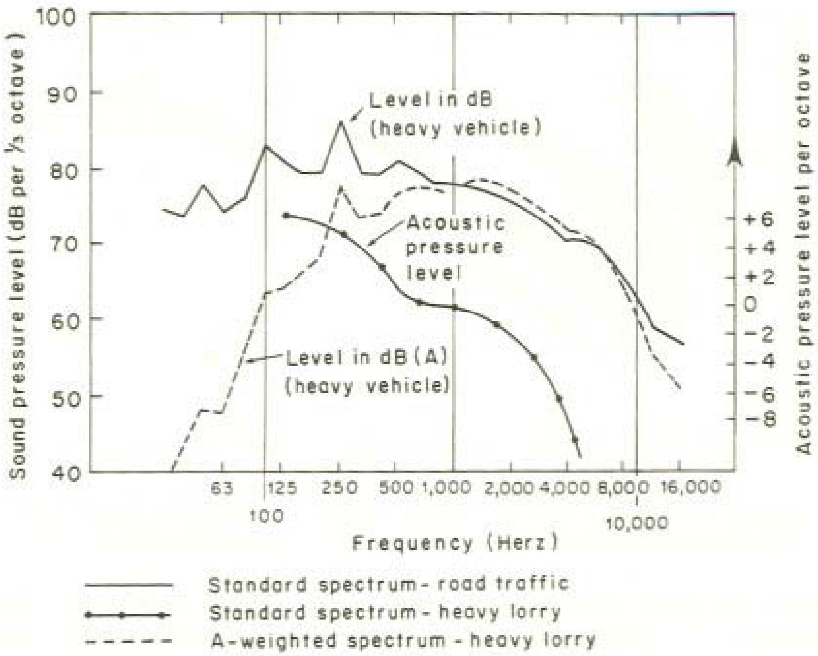


Figure 12.6

neglecting any air absorption, we have:

$$L_p = L_w - 10 \log 4 \pi r^2$$

where

L_p is the acoustic pressure level at a distance of r from the source of noise

L_w is the acoustic power level of the source of noise

If we consider a source of noise that is close to the sound-reflecting surface of the ground and assume that this source radiates in all directions in the upper hemisphere we have:

$$L_p = L_w - 10 \log 2 \pi r^2$$

Let L_p be the maximum acoustic pressure level recorded during the passage of a road vehicle. In practice, it should be noted that we measure the acoustic power in dB(A) at the standard distance of 7.5 metres from the vehicle. If L_w is the acoustic power level of the vehicle we have:

$$L_{p\,7.5} = L_w - 10 \log 2\pi (7.5)^2$$

$$L_{p\,7.5} = L_w - 25.5$$

If L_0 is the acoustic pressure level at a distance d_0, we have:

$$L_p = L_0 + 20 \log \frac{d_0}{d}$$

Whereas in referring to an acoustic pressure level for a source of noise we need to specify the distance from the source of noise at which this pressure is measured, this is not the case for the acoustic power. It should be noted here that at large distances from the vehicle of more than 100 metres, and where there is a ground effect, the above equations are no longer valid.

Table 12.3 Typical acoustic power and pressure levels

Vehicle	Acoustic power (watts)	L_w	L_p at 7.5 metres
Heavy lorry*	0.3	115	90
Car	0.03	105	80
Sound-proofed car	0.01	100	75
Normal speech	10^{-5}	70	45

* Maximum size allowed by the regulations.

B. *Statistical Distribution of Vehicle Acoustic Power*

In calculating the noise levels in the vicinity of road traffic it is useful to be able to refer to an established statistical distribution and hence an average value for the acoustic power for each type of road vehicle. The distribution curves given by the following Figure 12.7 show that there can be differences of up to 25 dB(A) approximately between the levels of noise emitted by isolated vehicles for similar speeds.

In practice, it can be used as a simple relationship between the mean acoustic power level and the speed for cars and heavy trucks:

$$L_w = a + b \log v \qquad [v \text{ km/h}]$$

For traffic moving at a steady speed on level roads:

Car with	$v < 40$ km/h	$a = 80$	$b = 10$
	$v > 40$ km/h	$a = 47$	$b = 30$

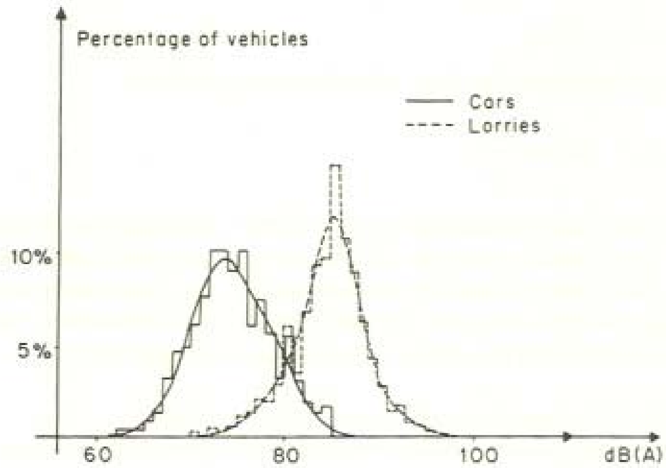


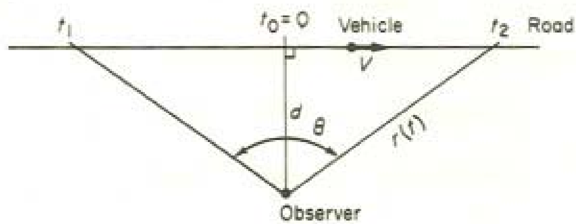
Figure 12.7 Distribution of noise levels for light and heavy vehicles in terms of L_{max} recorded at a distance of 7.5 metres from the vehicle as it passes by the microphone (for 621 cars and 566 trucks at steady speeds comprised between 60 and 80 km/h (Favre, B, 1977, IRT-CERNE)

Heavy trucks: with $v < 50$ km/h	$a = 110$	$b = 00$
$50 < v < 70$ km/h	$a = 93$	$b = 10$
$v > 70$ km/h	$a = 58$	$b = 29$

C. *Evaluation of* L_{eq} *in the Case of a Straight Section of Road*

The value of L_{eq} at the side of the road over a period of time T due to the passing of an isolated vehicle depends on the maximum noise level L_{max}, on the speed of the vehicle and — particularly in the case of heavy lorries — on the directional characteristics of the noise radiating from each of the different sources of noise on the vehicle.

We assume here that the vehicle can be regarded as a uniformly radiating point source of noise of constant acoustic power and that the vehicle is moving at a constant speed along a straight line.



The value of L_{eq} for the period of time t_1 to t_2 is then given by:

$$L_{eq} = 10 \log \int_{t_1}^{t_2} \frac{p^2(t)}{p_0^2} \, dt$$

where:

$p(t)$ = the instantaneous acoustic pressure
p_0 = the reference acoustic pressure

We also have:

$$p^2(t) = \frac{W \rho_0 c}{2\pi r(t)}$$

where

W = the acoustic power of the vehicle
ρ_0 = the air density
$r(T)$ = the distance of the vehicle from an observer at the point 0 at time t

We can accordingly write for the arithmetic mean of p^2 over the period of time t_1 to t_2:

$$|p^2|_{t_1}^{t_2} = \frac{1}{t_2 - t_1} \frac{W \rho_0 c}{2\pi} \int_{t_1}^{t_2} \frac{dt}{r^2(t)}$$

where:

$$r^2(t) = d^2 + V^2 t^2$$

Whence, given that θ is the angle subtended at the point 0 by that part of the vehicle trajectory covered during the period of time t_1 to t_2, we have:

$$\int_{t_1}^{t_2} \frac{dt}{r^2(t)} = \frac{\theta}{Vd}$$

so that:

$$|p^2|_{t_1}^{t_2} = \frac{1}{t_2 - t_1} \frac{W \rho_0 c}{2\pi} \frac{\theta}{Vd}$$

whence, for the period of time t_1 to t_2, we have:

$$L_{eq} = L_W - 10 \log (t_2 - t_1) - 10 \log dV + 10 \log \frac{\theta}{2\pi}$$

If we consider the maximum pressure level recorded at a distance d_0 from the source of noise, we have for the same period of time:

$$L_{eq} = L_{p_0} + 10 \log \frac{\theta \, d_0}{(t_2 - t_1)V} + 10 \log \frac{d_0}{d}$$

where distances are measured in metres and time in seconds.

Thus, given the maximum sound-pressure level recorded at a point 0 due to a passing vehicle, or knowing the acoustic power level, we can evaluate L_{eq}. It will be noted that:

— L_{eq} increases with 10 log θ, where θ is the angle subtended by the section of the road from the point of view of the observer.
— L_{eq} decreases with 10 log d_0/d, where d is the distance from the vehicle to the road (absorption being neglected). If we double the distance from the vehicle to the road, the value of L_{eq} is reduced by 3 dB.

For a source generating the same level of noise whatever the speed (L_w = constant), the acoustic energy received will decrease in proportion to the inverse of the speed V. This is consistent with the fact that the faster it passes by the less will the observer be exposed to the effects of the moving source of noise. However the acoustic power level L_w (or the maximum sound pressure level $L_{p\ max}$) itself varies with the speed. For a variation of 30 log v in this level, as can arise in the case of cars and heavy lorries running at speeds in excess of 60 km/h), (see Section 12.13B) it will be found that L_{eq} varies as a function of the speed V as 20 log V.

Assuming no variation in the value of L_w, which is an acceptable approximation for heavy vehicles at low speeds (Section 12.13B), it will be found that L_{eq} varies as:

10 log V

12.2 NOISE DUE TO ROAD TRAFFIC

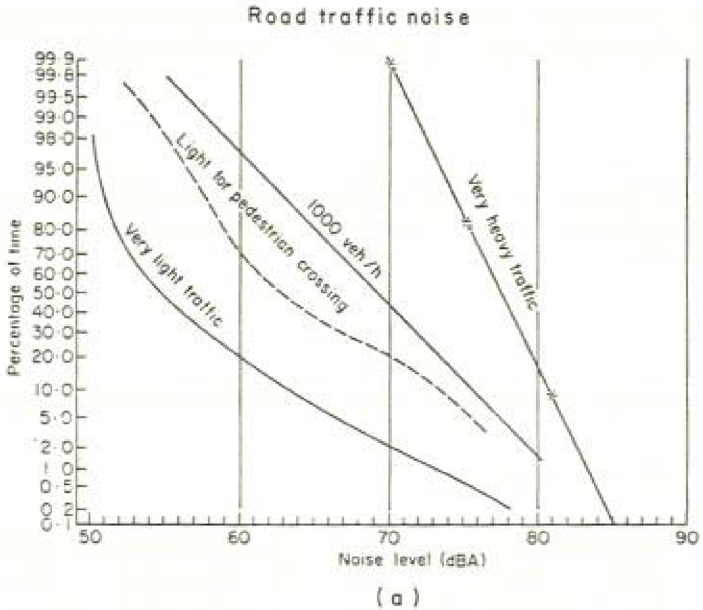
12.2.1 Statistical Distribution of Traffic Noise Levels

The noise due to the traffic along a road is continuously fluctuating with time and it is not easy to quantify such noise. One technique is to consider the statistical distribution of the noise levels observed during a given period of time. The dispersion of the noise levels decreases very much with the flow of traffic and the distance of the observer from the road. The graphs of Figure 12.8 show some cumulative distributions of noise levels — histogrammes are seldom considered here.

12.2.2 Evaluation of L_{eq} Due to the Passing of a Series of Vehicles — Steady Traffic

A. Evaluation in the Case of Identical Vehicles

Let the mean square acoustic pressure during the period of time t_1 to t_2, due to



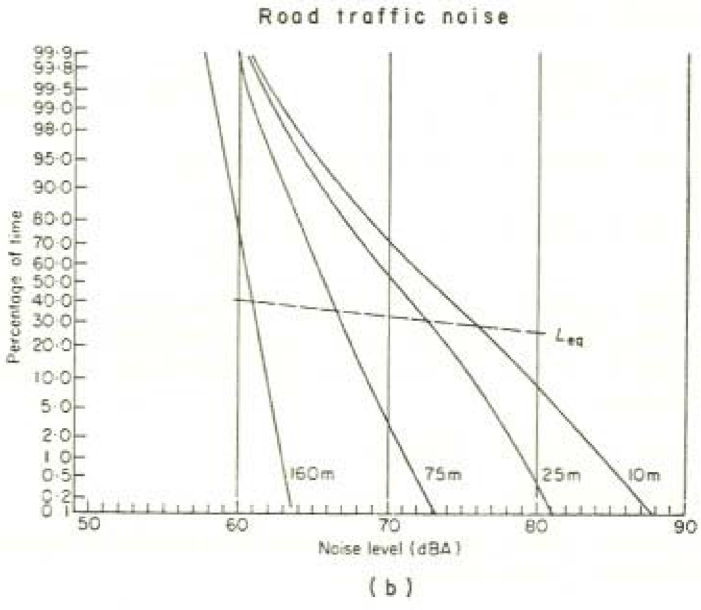


Figure 12.8 Noise level distribution at the roadside for: (a) Four types of traffic; (b) Different distances from the road (Alexandre *et al.*, 1975)

the traffic made up of a series of identical vehicles running through a road section subtending an angle θ, as seen by the observer be given by:

$$|p^2|_{t_1}^{t_2}$$

If we assume that for the series of vehicles on the road section, the mean square acoustic pressure for a vehicle i, during the same period of time t_1 to t_2, can be represented by:

$$|p_i^2|_{t_1}^{t_2}$$

then we can write, given that the different noise sources are not coherent:

$$|p^2|_{t_1}^{t_2} = \sum_i |p_i^2|_{t_1}^{t_2} = n|p_i^2|_{t_1}^{t_2}$$

where n is the number of vehicles that will have passed through the road section during the period of time t_1 to t_2, this number being given by $Q(t_2 - t_1)$, Q being the flow of vehicles, and where the period of time t_1 to t_2 is large in comparison with the time taken for a vehicle to pass through the road section.

For a vehicle i we have:

$$L_{eq} = 10 \log \frac{|p_i^2|_{t_1}^{t_2}}{p_i^2} = L_w - 10 \log (t_2 - t_1) - 10 \log Vd + 10 \log \frac{\theta}{2\pi}$$

so that for the complete series of vehicles we can write:

$$L_{eq} = L_w + 10 \log Q - 10 \log Vd + 10 \log \frac{\theta}{2\pi}$$

If the traffic is steady, L_{eq} is no longer dependant on the duration of measurement so that this latter does not need to be specified.

If the angle $\theta = \pi$ and if Q is expressed in vehicles/hour, V in km/h and d in metres we have:

$$L_{eq} = L_w + 10 \log Q - 10 \log Vd - 33$$

It should be noted that:

— If L_{eq_i} is the L_{eq} due to the passing of an isolated vehicle having an acoustic power level L_w, then we have:

$$L_{eq} = L_{eqi} + 10 \log Q$$

— If the value of L_w is independent of the speed (urban traffic) then L_{eq} decreases as the speed increases according to $-10 \log V$.

— When the rolling noise is dominant, and allowing for the way in which the values of L vary as a function of the speeds of the vehicles (see Section 12.1.1*C*), it will be found that for a given flow of traffic, L_{eq} increases with speed according to 20 log V.

B. Evaluation in the Case of Equi-spaced Vehicles of Different Acoustic Power Levels

If the vehicles do not have the same acoustic power levels then calculations similar to those carried out for the previous case show that:

$$L_{eq} = \bar{L}_w + 10 \log Q - 10 \log Vd + 10 \log \frac{\theta}{2\pi}$$

where:

$$\bar{L}_w = 10 \log \frac{(1/n) \sum_i w_i}{wo}$$

$\bar{L}_w$ being the averageof the acoustic power levels of the different vehicles. *wo* being the reference of the acoustic power.

In the case where the reference is made to the acoustic pressure level L_0 of the vehicles at a given distance d_0 then L_{eq} can be evaluated on assuming a normal distribution for the acoustic pressure levels for the different vehicles.

Let the probability density be:

$$P(L_0) = \frac{1}{\sigma\sqrt{2\pi}} \, e^{-[(L_0 - \bar{L})/2\sigma^2]}$$

where $\bar{L}$ is the mathematical expectation for the value of L_0 estimated in terms of the arithmetic mean of the L_0 values for the different vehicles.
It can be shown that (Barry and Reagan, 1978):

$$L_{eq} = L_0 + 0.115\sigma^2 + 10 \log Q - 10 \log Vd + 10 \log \frac{\theta}{2\pi} + 10 \log 4\pi \, d_0^2$$

where:

L_0 = the arithmetic mean of the acoustic pressure levels due to the individual vehicles at a distance of d_0 in metres
σ = is the standard deviation of these levels
V = the speed of the series of vehicles in metres per second
Q = the flow of traffic in vehicles per second

The assumption of a normal distribution for the acoustic power levels of

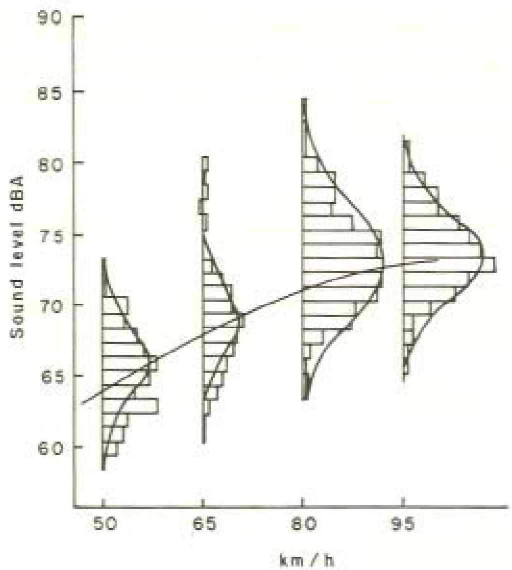


Figure 12.9 Distribution of Noise emission levels for different types of cars as a function of speed

vehicles of the same type is acceptable providing that they are all travelling at the same speed (Figure 12.9).

If the traffic is made up of different types of vehicle we can make use of the following type of equation:

$$L_{\text{eq.total}} = 10 \log \left(10^{L_{eqc}/10} + 10^{L_{eql}/10} + 10^{L_{eqb}/10}\right)$$

where L_{eqc}, L_{eql} and L_{eqb} are the levels applying to cars, heavy lorries and buses respectively.

12.2.3 Evaluation of L_{eq} in the Vicinity of a Highway

It is evident from what was said in par. 12, 21 and 22 that the acoustic energy emitted by road traffic is a function of:

—The flow of vehicles.
—The speed of the vehicles in terms of an average value and the dispersion.
—The percentage of heavy lorries making up the traffic.
—The gradient r in terms of the change of height for a given displacement along the length of the road.

Clearly, the most rapidly moving vehicles will have a predominant effect but speed limits and the increasing number of vehicles on the roads lead to a restriction in the range of speeds that can arise. In practice, we simply note the speed that is exceeded by 15% of the vehicles.

A wide range of heavy vehicles are employed but given the automatic traffic counting systems that are in operation, we limit our attention to vehicles having a Gross Vehicle Weight in excess of 3.5 tonnes. We can also make use of an acoustic equivalent factor E in terms of the number of cars which, under given traffic conditions, emit the same acoustic power as a heavy lorry:

Table 12.4

	Acoustic equivalent factor E for different gradients				
Type of road	$r \leqslant 2\%$	$r = 3\%$	$r = 4\%$	$r = 5\%$	$r \geqslant 6\%$
Motorway	4	5	5	6	6
Urban highway	7	9	10	11	12
Urban road (boulevard, etc.)	10	13	16	18	20

It should be noted that the contribution of heavy vehicles to the noise is very variable. It depends on the speed of the traffic and it is relatively small when the traffic is running regularly and at high speed since the cars will then be travelling at sensibly higher speeds than the heavy vehicles and emitting comparable levels of noise.

The direct effect of the heavy vehicles can be evaluated in terms of the increase K_{hv} in the value of L_{eq} for the traffic noise compared to the value that would apply if the traffic has been made up simply of cars for the same total flow of traffic. Thus the graph of Figure 12.10 shows what correction needs to be made to the value of L_{eq} due to traffic made up of light vehicles only in order to take account of a given percentage of heavy vehicles for different types of road. An indirect effect of the presence of heavy vehicles can be to result in a slowing down of the traffic such that, in practice, an increase in the percentage of heavy vehicles making up the traffic can result in only a small increase in the noise level in the vicinity of a highway.

Evaluation of $L_{eq\ A}$ in the vicinity of a highway. At the points in a free field, where the only sound received is that coming directly from the traffic, we can calculate the value of L_{eq} at a distance d from the road on giving L_w its value as a function of vehicle speed, as indicated by Section 12.1.2*A*. Thus for vehicle speeds in excess of 60 km/hour we have:

$$L_{eq\ A} = 10 \log Q + 20 \log V - 10 \log d + 10 \log \frac{\theta}{\pi} + 14$$

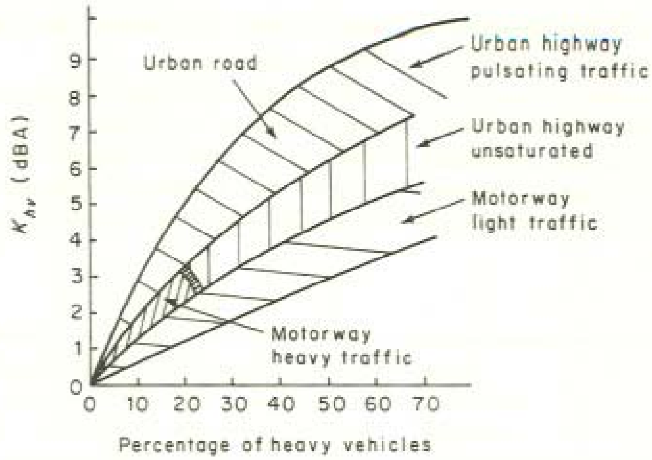


Figure 12.10 Effect of the presence of heavy vehicles on the value of L_{eq}. Correction to be made in comparison with the value due to traffic made up entirely of light vehicles

On taking account of the width of the road, the acoustic equivalent factor E for the heavy vehicles and any corrections for the effects of a gradient and the type of road surface we arrive at the complete equation:

$$L_{eq\ A} = 10 \log (Q_{lv} + EQ_{hv}) + 20 \log V - 10 \log \left(d + \frac{w}{3}\right) + 10 \log \frac{\theta}{180} + K_r + K_c + 14$$

where:

Q_{hv} = The flow of heavy vehicles per hour
Q_{lv} = The flow of light vehicles per hour
E = The acoustic equivalent factor given in the previous section
V = The speed of the traffic in km/hour
d = The distance to the edge of the road in metres
w = The width of the road in metres
θ = The angle subtended by the observed section of road in degrees
K_r = A correction factor to take account of any gradient
K_c = A correction factor to take account of the type of road surface

12.3 NOISE PROPAGATION AND GROUND EFFECT

12.3.1 Propagation of Noise in the Case of an Open Site

The distance to the outer edge of the road is generally considered to range from 5 to 300 metres so that in practice the most important effect with regard to the propagation of the noise, apart from that due to the geometrical divergence, is that due to the presence of the ground, given that the atmosphere is assumed to be generally stable and of uniform composition.

The effect depends very much on the nature of the ground and the equations employed to predict the value of L_{eq} in the vicinity of main roads tend to be based on a relationship for the decrease in noise level with distance lying somewhere between that due to the geometrical divergence and involving the term $1/r$ and an inverse square law involving the term $1/r^2$. A common practice is to assume an attenuation of 4 dB for each doubling of the distance from the source of the noise, i.e. a relationship involving the term $1/r^{1.3}$, and the equation:

$$L_{eq\ d} = L_{eq\ d_i} - 13 \log \frac{d}{d_i}$$

where d and d_i are two distances from which the respective noise levels are to be compared.

In the case of the L_n noise indices, the rate of decrease with distance becomes more marked in going from L_{99} to L_1, as shown by the graph of Figure 12.11:

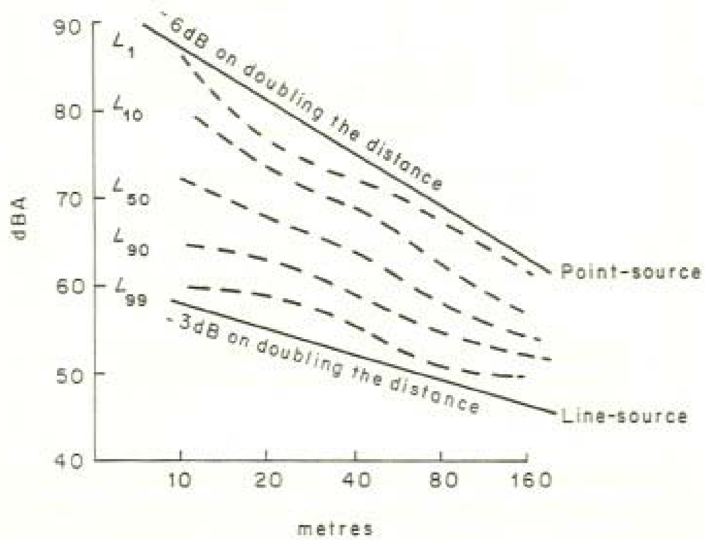


Figure 12.11 Attenuation of the L_1, L_{10}, L_{50} and L_{99} indices with distance (traffic of 2,200 vehicles per hour)

Thus the peak levels are attenuated more rapidly and the fluctuations in the acoustic pressure levels reduced as the distance from the source of noise is increased. There is little change in the frequency spectrum of the noise except for a greater attenuation in the 1,000 to 2,000 Herz range due to air absorption and the ground effect (see Figure 12.12).

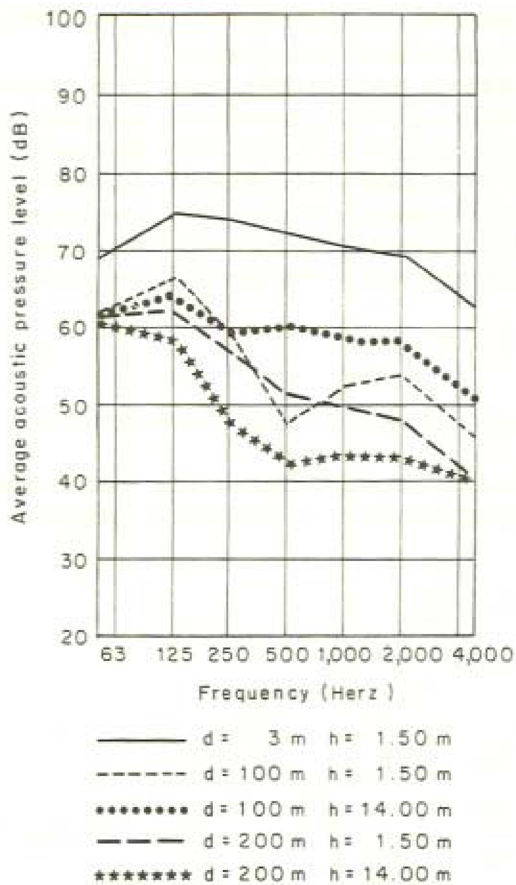


Figure 12.12 Variations in the frequency spectrum of the noise with distance and height of receiver (grass land)

Finally, it should be noted that the degree of attenuation depends on the height above ground of the point of reception, the difference here being greater to the extent that the ground effect is more pronounced (see Figure 12.13).

12.3.2 Effects of the Transverse Profile of a Site on the Propagation of Traffic Noise

For roads going through a cutting or those that are very much enclosed, it is possible to evaluate the diffraction effects on employing the procedure referred to in a following section of this paper concerned with noise screens. Unfortunately, as in the case of the provision of noise screens, it is difficult to

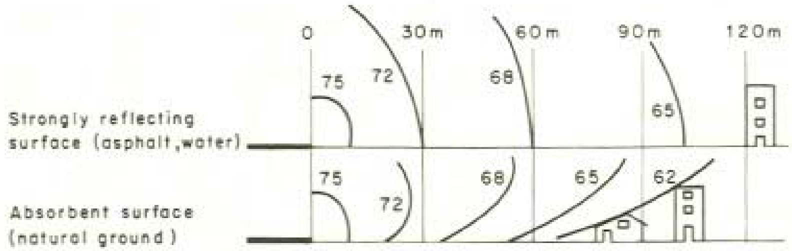


Figure 12.13 Isophones for different ground surfaces, at various distances from the road

allow for the effects due to the varying degree of absorption of the side slopes in carrying out the calculations. See classical works on diffraction by barriers (Maekana, 1965; Jonasson, 1972; Kurze, 1971).

The evaluation of possible solutions must, of course, take account not only of the effectiveness of the noise screens but also of the costs of any occupation of land and of carrying out civil engineering work. When the layout of the site allows, it is sufficient to enclose the road in a shallow cutting bounded by a bank to the side such that there is no net displacement of soil. The Figure 12.14 shows the shape of the isophones for different transverse profiles. In the case of enclosed roads, the absorbent materials that are provided operate in accordance with the same principles that apply in the case of the provision of noise screens. The provision of embankments cancel out any ground effects but as a compensation it will be found that screens of a given height are more effective.

12.3.3 Noise Levels in the Case of a Street with High Buildings on Each Side

The reflection of sound from the front faces of buildings to each side of a street modifies the acoustic field, at least in the vicinity of these faces, giving rise for a sufficiently high h/d ratio to a reverberation enclosure (see Figure 12.15). The acoustic field can be considered to include an infinite number of image sources located above ground level.

Assuming that the equivalent absorbing surface for the street is essentially the overhead opening then the noise level for the reverberating enclosure, where L_w is the acoustic power level of the sources, is given by:

$$L_p = L_w - \log d + \text{constant}$$

Whereas in practice the h/d ratio may not be very great (less than 1), experimental results show that for $h/d > 0.2$:

—The value of L_p at the front face of a building varies as a function of $-10 \log d$.

—The value of L_p decreases only very slightly as the height of the receiving

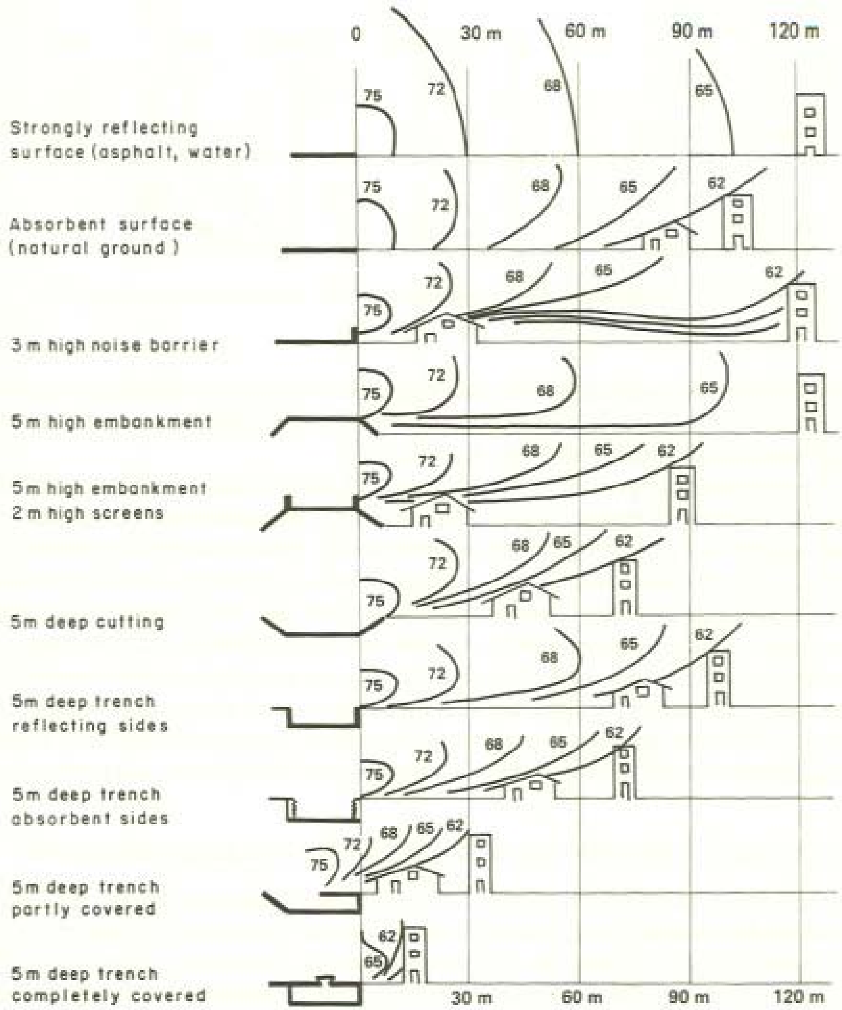


Figure 12.14 Effect of different transverse profiles and means of protection from noise. Equal noise level curves or isophons. The isophon values shown are for the L_{eq} in dB(A) for a traffic of 2,000 vehicles per hour. Position of a house and/or a three-storey building for an L_{eq} of 62 dB(A) at the facades

point on the front face of a building above ground is increased (reduced importance of direct radiation).

12.4 METHODS FOR PREDICTING NOISE LEVELS

12.4.1 The Different Methods that can be Employed

In general, the different methods that can be employed to determine the L_{eq} levels for road traffic noise are as follows:

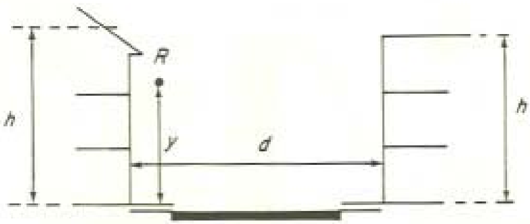


Figure 12.15

d = width between facades
h = effective height of buildings
y = height of reception point above road surface
All distances in metres

— Use of the equations considered above.
— Manual methods based on the use of equations and graphs.
— Office calculator procedures.
— Use of computer programs.
— Use of reduced scale models operating in air or water.

The equations considered in the previous sections of this paper cannot be used when the composition of the traffic and/or the arrangement of the buildings and the topography of the site are too complicated. Simple programs, compatible with the capacities of office calculators can be employed in studying quite complicated cases, particularly when it is a matter of determining the effectiveness of noise screens but such programs cannot normally be employed in dealing with more than two dimensions in the plane perpendicular to the road. When multiple reflections are involved it is necessary to make use either of computer programs or of reduced scale models. The computer programs can include subroutines that define the composition of the traffic that is involved.

12.4.2 Use of Computer Programs in Predicting Noise Levels

Computer programs for use in the evaluation of noise levels are now available in a number of countries, the structure of these programs being very varied (Barry and Reagan, 1978; Göteborg OCDE, 1979; Lamure, 1981). The level of the noise at a point in the vicinity of a road depends on:

— The characteristics of the traffic and the road which determine the average acoustic power levels of the emitted noise.
— The characteristics of the site which influence the way in which the noise is propagated.

The parameters that are considered are:

— The flow of traffic in vehicles per hour.
— The composition of the traffic (proportion of heavy vehicles).

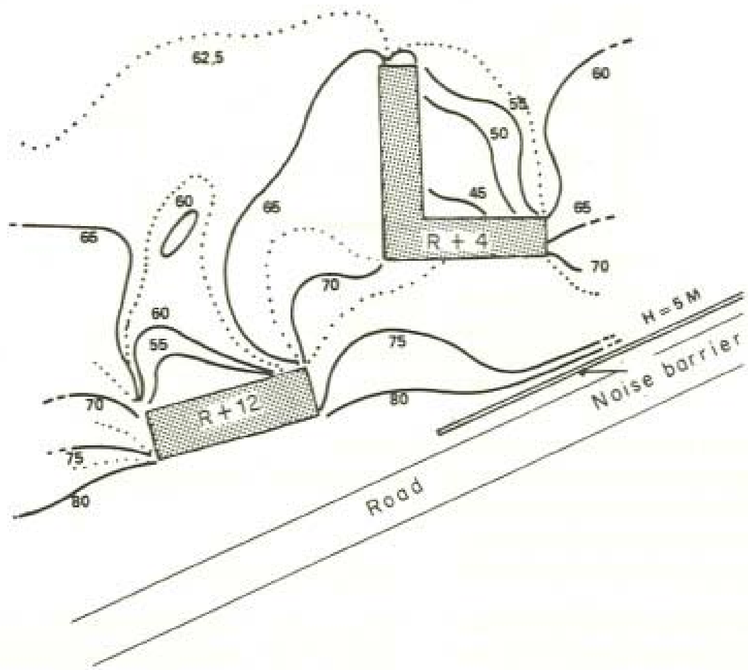


Figure 12.16 Noise contour map produced as a result of making use of a computer program (IRT-CERNE program)

—The average speed of the traffic.
—The degree to which the traffic is flowing smoothly where applicable.
—The type of road surface and the gradient involved.

The acoustic power for each section of road is determined on following the same procedure that was employed in deriving the equations considered in the previous sections of this paper.

Thus, in making use of a computer programme it is possible to plot the isophones for a built-up site.

12.4.3 Use of Reduced Scale Models in Predicting Noise Levels

Reference can be made to a number of different laws of similarity in making use of reduced scale models. For example, we can simulate the acoustic conditions in air on transposing the noise frequencies that are involved. Thus the ratio between the length of the sound waves and the dimensions of the site (λ/α) can be retained on reducing these dimensions by a factor e and on multiplying the frequencies by e.

The most common practice is to employ a scale reduction factor of about 1/100. A greater reduction than this would involve working at very high frequencies such that, given the absorption of the sound waves in air, the simulation would break down. In any case, a scale reduction of about 1/100 calls for the model to be operated in a room where the humidity of the air is kept to a very low level in order to avoid any excessive absorption of acoustic energy which needs to be radiated at very high frequencies (of about 20,000 to 200,000 Herz) in order to ensure the simulation.

12.4.4 Comparison of the Different Methods of Predicting Noise Levels

The noise conditions can be evaluated on making use of one of the predicting methods mentioned above and also, in some cases, on carrying out a series of measurements. These latter have the advantage of yielding accurate results but only where the source of noise considered is both stable and dominant. Traffic characteristics, of course, change with time and the measurements must accordingly take account of variations in the rate of flow and the speed of traffic and the percentage of heavy vehicles involved. It should also be noted that the measurements can be affected by the weather conditions and that they need to be carried out by experienced personnel. The main advantage of carrying out measurements is that it is possible to determine the results of effects which are not amenable to calculation and that are concerned to some extent with ground effects or diffraction of the sound waves around obstacles of complicated shape. There is also the fact that the results of measurements can have a better psychological impact.

In fact, in carrying out their project studies, engineers and town planners generally make use of the methods serving to predict noise levels and measurements are carried out simply with a view to evaluating the initial conditions.

The selection of the appropriate method can be a difficult matter and depends on the objectives involved. Table 12.5 shows the potential of the different methods with respect to different criteria while referring to what are termed manual calculating methods of varying degrees of complexity, such methods being described in different publications such as the FHWA Highway traffic noise prediction model, (Barry and Reagan, 1978), the Guide du Bruit des Transports Terrestres (Ministère des Transports, Paris, 1980). In all cases, the use of simple methods, in the first instance, with a view to outlining the problem or identifying critical points, is recommended.

12.5 METHODS FOR REDUCING NOISE LEVELS IN THE VICINITY OF A MAIN ROAD

12.5.1 The Different Methods that can be Employed.

The following can be considered with a view to reducing the impact of noise in the vicinity of main roads:

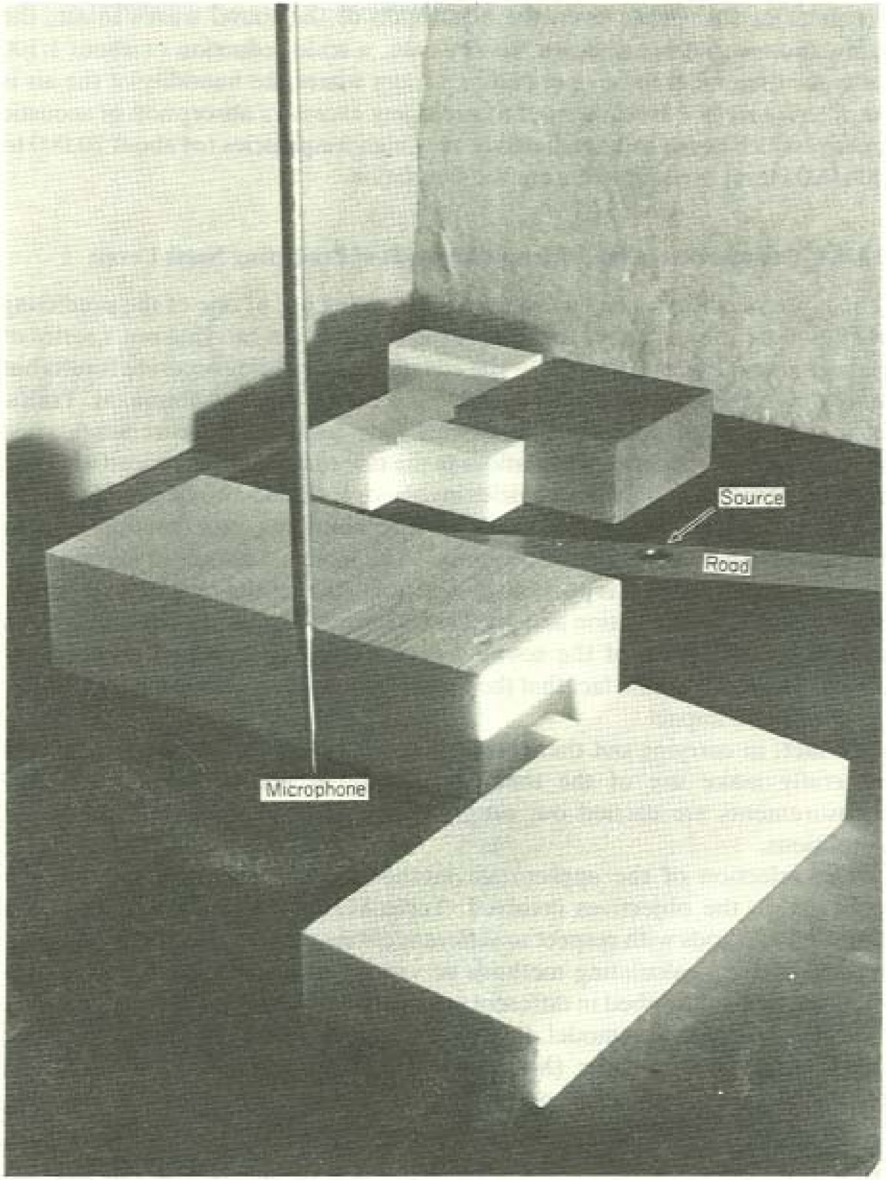


Figure 12.17 Study of a site at the CSTB modelling Centre, Grenoble

— Sound proofing of the vehicles.
— Reduction of the rolling noise at the point of contact between the tyre and the road surface.

Table 12.5 Comparison of the different methods that can be employed in estimating noise levels

Criteria	The different methods available to predict noise levels				
	Measurement	Use of equations and graphs	Calculation	Use of computer programs	Use of models
Accuracy in normal use (dBA)	± 1.5	± 3		± 2	± 2
Form of results	For a particular point in time	Outline results	For a particular point. Optimization possible	All forms. Optimizations	Complete but no optimization
Approximate cost ($)	200 to 1,000 per point			2 to 2,000 per case	20,000 per case
Time taken	2 days	1 day	1 day	2 weeks	2 months
Flexibility:					
Study of variants					
Re-adjustment to take account of results of any measurements			Fairly good	Good	Fairly good
Ease with which results can be distributed	Average	Good	Good	Average	Mediocre
Educational value	Good	Good	Mediocre	Poor	Very good

— Action with respect to the road traffic itself and in particular the vehicle speeds.
— Action in connection with the design of the roads insofar as the longitudinal and transverse profiles are concerned.
— Provision of noise screens.
— Sound proofing of existing buildings.
— Town planning and issue of building permits.

Clearly, the method that needs to be employed depends on the particular case which can involve any one of the following situations:

(i) Road and buildings already in existence.
(ii) Road to be constructed through an existing built-up area.
(iii) Buildings to be constructed in the vicinity of a road.
(iv) Both road and buildings to be constructed.

More and more possibilities for reducing the noise levels become available in going from situation (i) to (iv). Before any buildings have been constructed the main solutions that need to be considered are those associated with town planning and the issue of building permits. However, even in situations (iii) and (iv), it is worth considering the provision of appropriate longitudinal and transverse profiles for the road or the installation of noise screens in order to avoid any unnecessary restrictions with the regard to town planning or the availability of building land.

Not many countries resort to legislation in imposing technical constraints on road construction companies or requiring them to consider the question of compensation but it is common practice to issue recommendations. In addition to this, engineers and town planners are under increasing pressure to take account of the reactions of people living in the vicinity of existing roads or of roads that are to be constructed.

12.5.2 Reduction of Noise Levels on Limiting Traffic Speeds

It should be noted (Section 12.1.3*c*) that for speeds greater than 60 km/h and in the case of light vehicles (steady speeds):

L_w and L_{max} vary with 30 log V
L_{eq} varies with 20 log V

In the case of heavy vehicles, variation of the same order can be observed for speeds greater than 70 km/h. At medium speeds (50 to 70 km/h), L_w and L_{max} vary with 10 log V and L_{eq} remains practically constant. It should be noted however, that V is an average speed that accordingly needs to be distinguished, from the maximum speed. A reduction in traffic speed can therefore result in a smaller reduction in noise level than that predicted by the previously mentioned equations.

A. Case of Traffic not Containing any Heavy Vehicles (low, unsteady speeds).

For speeds lower than 60 km/h, L_{eq} may decrease as speed increases. The dispersion of vehicle speeds can lead to an L_{eq} value that is 1 to 2 dB(A) greater than the value that would be obtained on assuming that all vehicles are running at the average speed for the traffic. However, it should be noted that as soon as a speed limit is in operation, the law for the distribution of the speeds of the individual vehicles is modified and we no longer know what is the relation between the maximum speed V_{max} and the average speed for all vehicles V.

It should be noted that for speeds less than 60 km/h, an increase in average speed can lead to a reduction in atmospheric pollution and the consumption of fuel (see Figure 12.18). We need to make a distinction here between the operation of vehicles in low speed urban areas, where the speeds remain below 60 km/h, and the circulation of traffic on main roads.

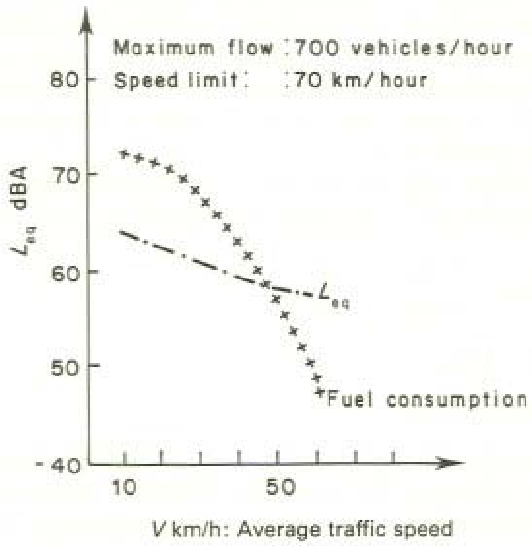


Figure 12.18

B. Case of Traffic Including a Proportion of Heavy Vehicles

Heavy vehicles normally circulate at lower speeds than do light vehicles and their acoustic power is not very dependent on their speed. The presence of such vehicles accordingly limits the effectiveness of any reduction in traffic speed. In fact, it is necessary to reduce the speed of the traffic by an appreciable amount in order to obtain a reduction in noise levels of only a few decibels as is indicated by the following table:

Table 12.6

Speed limit (km/h)		Reduction of noise according to the percentage of heavy vehicles making up the traffic (dBA)			
Light vehicles	Heavy vehicles	0%	10%	30%	100%
90	80	3 to 4	2	1	0
90	60	3 to 4	3 to 4	3 to 4	2 to 3
60	60	7 to 9	7	5	2 to 3

12.5.3 Reduction of Noise Levels on Limiting the Circulation of Traffic

This limitation, which normally applies during certain times of the day or week, is usually applied to the circulation of heavy vehicles. The degree to which such a restriction can be effective in reducing the L_{eq} value in the vicinity of highways can be determined on making use of the equation given in Section 12.2.3, where L_{eq} is expressed as a function of the percentage of heavy vehicles making up the traffic.

If we let H_0 be the original, and H' the final percentage of heavy vehicles making up the traffic, the reduction in the value of L_{eq} will amount to:

$$L_{eq} = 10 \log \frac{1 + H_0(E - 1)}{1 + H'(E - 1)}$$

If $H' = 0$ and $E = 10$ we have:

$$L_{eq} = 10 \log (1 + 9 H_0)$$

Thus the value of L_{eq} will be reduced by at least 3 dB(A) when $H_0 \geqslant 10\%$.

For average traffic speeds of more than 100 km/h, the coefficient E, giving the number of light vehicles equivalent to one heavy one, will fall since the speed of the former will be very much greater than that of the latter. The value of E can be obtained from the Table 12.4 given in Section 12.2.3.

12.5.4 Provision of Noise Screens

A. *Definitions*

A noise screen is a structure designed to reduce the acoustic pressure levels in sensitive zones that are exposed to noise from a particular source. In some favourable cases structures that are designed for other purposes, such as buildings, can also serve as noise screens.

The effectiveness of a noise screen for a *given site and reception point* is defined as the difference between the acoustic pressure levels in the absence and following the provision of that screen. In the case of the screening of traffic noise, the atmosphere is assumed to be undisturbed and of uniform composition. The difference between the L_{eq} values for a given type of traffic is normally expressed in the form:

$$\Delta L_{eq} = L_{eq.\,ns} - L_{eq.\,s}$$

where $L_{eq.\,ns}$ is the value of L_{eq} in dB(A) for the given type of traffic in the absence of a screen and $L_{eq\,s}$ the value of the same parameter after the screen has been installed.

In some cases, for example when we are mainly interested in the peak noise as in the case of rail traffic, we can consider the effectiveness of the noise screen with respect to other noise parameters such as L_1 or the L_{NP}.

In the case of traffic with which we are normally concerned, and which can be regarded as originating from a number of identical and regularly distributed sources of noise, the effectiveness of the noise screens does not depend either on the speed or the rate of flow of the vehicles but only on the proportion of heavy vehicles making up the traffic, given that these latter, in comparison with cars, consist of sources of noise that are at a higher level above ground level and that radiate a greater degree of noise at the lower frequencies.

The way in which the screen needs to operate depends to a large extent on the layout of the site where it is installed. At the very least it must block any direct, propagation of traffic noise from the road concerned. In the case of a reflecting ground surface the screen should also block any reflected propagation of noise. Other reflections, for example, off the faces of buildings or other surfaces (of bridges, supporting structures, etc.), can reduce the effectiveness of noise screens.

B. *Types of Screen*

The different types of noise screen most frequently employed are as follows:

- —Earth mounds.
- —Panels (made of wood or metal).
- —Walls.
- —Combination screens involving, for example, an earth mound and a wall or the facing of an embankment.
- —Noise absorbing screens.

Apart from their acoustic qualities and in particular a minimum mass per unit surface area, the noise screens must have a number of other qualities. Thus they must be able to withstand the effects of wind, be of durable constuction, be made from non-inflammable materials and have an acceptable appearance.

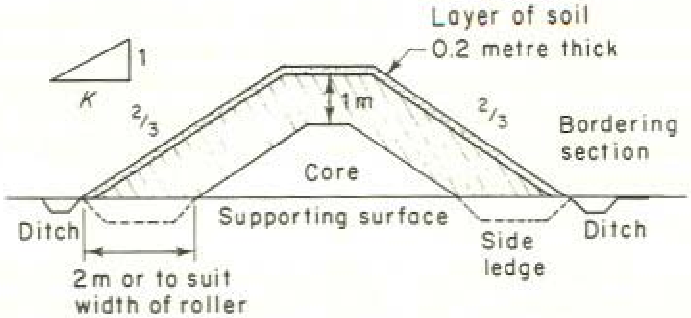


Figure 12.19 Earth mound

Safety requirements also lead to the need to locate the screens at a certain minimum distance from crash barriers, this distance depending on the degree to which such barriers are likely to be deformed in the event of an impact (a clearance distance of 1.5 metres is generally required). An exception to this clearance requirement arises in the case of structures that serve as both noise screens and crash barriers.

Absorbent screens are costly and seldom employed. They can be useful, however, in the case of sites where there can be reflections that destroy the effectiveness of a more normal type of screen or that result in the sound waves being propagated towards a sensitive zone (see Figure 12.20). The more normal solution to this problem however is found on inclining the existing noise screen from the vertical — an angle of inclination of 5 to 10° is usually sufficient.

The material employed in the noise absorbing screens needs to have a Sabine coefficient of absorption of about 0.6 over a frequency range of 250 to 2,000 Herz. The absorption must not be affected by the weather conditions or by solar radiation and there should be no risk of the material making up the screen becoming blocked with dust. The absorbent part of the screen can consist of a porous fibre, such as glass wool, etc., protected with glass wool fabric or a

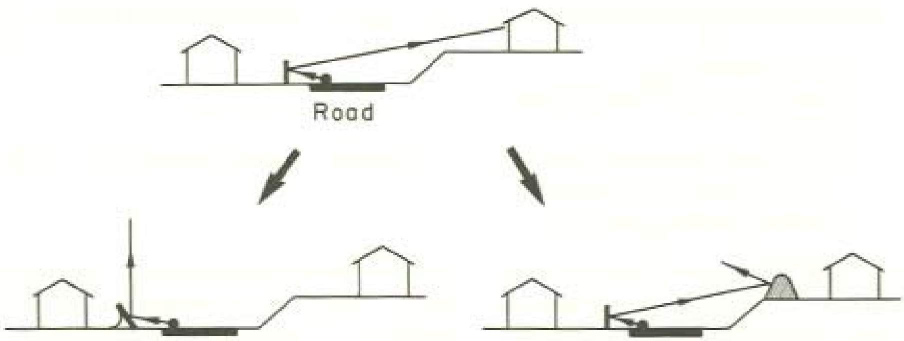


Figure 12.20

perforated plastic sheet (PVC) covered with another sheet of plastic material to keep out dust. This form of construction results in the provision of absorbent screens on open sites at a cost which can amount to as much as twice the cost involved in providing reflecting type screens.

Absorbent screens are more commonly provided in the case of locations where there is some protection from the weather such as tunnels, covered roads and underground railways systems, given that the screens themselves benefit from this protection and that reflecting type screens cannot be used in such locations.

12.5.5 Evaluation of the Effectiveness of Noise Screens

In the case of the evaluation of the effectiveness of the commonly employed type of screen made up of cylindrical elements having axes running parallel to the road, we can make a distinction between three different arrangements:

- —A thin screen located on an open site and overlooking a flat reflecting ground surface.
- —A thin screen located on an open site and overlooking a flat ground surface of given impedance.
- —A thick screen or one of complex shape located on an open site.

The theoretical works for the calculation of the sound reduction by thin screens has been made by several authors (Mackenzie, 1965; Jonasson, 1932; Kurze, 1971). So now we can evaluate the effectiveness of reflecting screens consisting of parallepipeds with vertical edges on making use of computer programs providing that the topography of the site and the shape of any associated constructions are of a simple nature.

In evaluating the effectiveness of screens of complex shape or that are installed on built-up sites or on sites of irregular topography it will be necessary to make use of reduced scale models.

If the ground surface cannot be considered as a reflecting plane then it will be necessary, in principle, to take account of a ground effect in any calculations made to determine the effectiveness of the screens. In unfavourable cases, the partial destruction of the ground effect due to the presence of the screen can result in an appreciable reduction in the effectiveness of the latter.

Reference should be made to the Chapter 14 (this volume) by M. Maeckawa in connection with the calculations that need to be made in determining the effectiveness of the screens.

12.6 REDUCTION OF NOISE LEVELS ON APPLYING TRAFFIC-CONTROL MEASURES IN BUILT-UP AREAS

12.6.1 Reduction of Noise Levels on Applying Conventional Traffic Control Measures

One approach in trying to reduce noise levels can be a matter of considering a more appropriate use of the road system.

The application of modern traffic or transport plans that allow heavy vehicles to follow routes that have been the subject of a careful study generally produced satisfactory results. However, the application can also lead to an increase in the level and degree of dispersion of noise. For example, the general introduction of one-way traffic, leading to higher vehicle speeds and the use of streets that did not previously carry much traffic, will not invariably lead to a lessening of the impact of noise.

Thus the Table 12.7 gives the values of different noise indices before and after the introduction of one-way traffic along three fairly heavily trafficked streets in the city of Lyon. It can be seen that the noise levels were increased in each case. On the other hand, there can be some relief in the case of certain traffic corridors through sensitive areas.

Table 12.7

	Index values					
	Street No. 1		Street No. 2		Street No. 3	
Index	Before	After	Before	After	Before	After
L_{eq}	73.6	81.2	74.2	79.5	69.3	76.2
σ	4.2	4.5	3.4	4.0	5.5	4.7
L_{NP} (or L_1)	84.1	92..2	82.6	89.5	83.3	88.2

An improved circulation of traffic leads, in the long run, to an increase in trip lengths, given that the average of such lengths is approximately proportional to $V^{1.5}$, where V is the average speed of the vehicles. The application of a policy favouring the circulation of traffic therefore leads to a double disadvantage since as well as the increase in noise levels an additional number of people are subjected to the nuisance. For the main roads it is found that the product of the number of people and the acoustic energy to which they are exposed in fact increases in proportion to V^4.

Other more effective traffic control measures that can be employed to reduce noise levels are as follows:

—Control of the circulation of heavy and two-wheeled vehicles.
—Application of speed limits and of restrictions concerning the circulation of traffic.
—Elimination of traffic intersections providing that this is not likely to lead to excessive increases in vehicle speeds.
—Changes in the operation of the public transport systems.

In considering the application of any of these measures it is important to pay attention to the possibility that local improvements could give rise to degradations elsewhere.

12.6.2 Reduction of Noise Levels on Limiting the Circulation of Heavy Vehicles

It should again be noted that:

1. Depending on the nature of the traffic involved, the passage of a vehicle of more than 3.5 tonnes GVW can give rise to a disturbance equivalent to that resulting from the passage of up to 40 cars (see Section 12.2.3).
2. The maximum level of noise radiated by vehicles of more than 3.5 tonnes GVW is not very dependent on their speed when this latter is less than 80 km/hour.
3. The value of L_{eq} due to the passage of a heavy vehicle is greater in cases where the vehicle is running at a low speed. Thus inclines and locations where vehicles start off on their trips can be sources of particularly undesirable effects.
4. Sound barriers are not so effective in the case of heavy vehicles since the higher chassis will mean that the barrier is effectively lower in height while the longer wavelength of the predominant low-frequency noise of the vehicle will mean that the barrier does not act as an effective obstacle.
5. The proportion of heavy vehicle traffic carried by the major roads tends to be greater in the evening, i.e. between 20.00 and 01.00 hours, and early in the morning.

The different actions that can be taken with a view to reducing the disturbance due to the noise of heavy vehicles are as follows:

(a) Divert the heavy vehicle traffic on to roads where few people are likely to be affected or at least on to roads where there are only a few traffic intersections. This will not lead to an increase in fuel consumption providing that it is possible to reduce the number of times that vehicles are obliged to halt without an excessive increase in the distance that needs to be covered (it should not be necessary to cover more than twice the original distance). It should be noted, however, that the diversions often result in the vehicles passing through peripheral districts of a town where they can be generally discontinuous developments of public and private housing where people are very sensitive to noise.

(b) In the case of large towns, prohibit the circulation of heavy vehicles other than on a defined network of roads except where necessary for access. The difficulties here are:

— The objections of people living along the roads making up the defined network. Public consultation is necessary here and this can lead to projects being abandoned in that their application would lead to a worsening of the situation for some people.

— The cost of applying the measures in connection with the loss of time and increased fuel consumption for the transport companies and the provision of road signs and signals and policing in the case of the local authorities.

Severe restrictions with regard to the routes that they are obliged to follow can lead to the transport companies acquiring smaller vehicles that they can use on all roads such that there will only be an improvement in the overall situation if these vehicles are quieter than the heavy vehicles that they will have replaced. In fact, under present conditions and for the transport of the same tonnage of goods smaller vehicles give rise to the same degree of disturbance as the heavy vehicles. Given these difficulties it would appear that we need to select road networks where it would be a simple matter to ensure that one of the following two restrictions were respected:

— Obligatory use of certain roads by the heaviest vehicles (e.g. more than 16 tonnes).

— Banning of all heavy vehicles (e.g. more than 3.5 tonnes) on certain roads.

It is clear that if vehicles could be classified according to a known and displayed noise level, as is the case for their tonnage, it would be possible to take more effective action.

(c) Prohibit the circulation of heavy vehicles during the evening and early in the morning on main roads going through densely populated areas. This restriction is sometimes imposed over the weekend which can be an advantage given that Saturday evenings and Sunday mornings are periods of time, among others, when people most want to be free of any disturbance.

During the week, unfortunately, the ban on circulation tends to be applied during the day which leads to movements of the heavy vehicles during periods of time when people are more sensitive to noise.

(d) Pay attention to a proper provision and location of vehicle terminals, goods depots and parking areas. The undesirable effects due to the circulation of heavy vehicles can be reduced when vehicle terminals and goods depots are located not in the centre of a town but close to ring roads. It should be noted here that the most common disturbance due to the presence of industrial establishments is that associated with the consequent circulation of heavy vehicles.

The provision of parking areas for heavy vehicles ensures that the vehicles are not parked or manoeuvred at night in residential areas.

12.6.3 Reduction of Noise Levels at Intersections

The way in which we quantify noise at traffic intersections, where vehicles are obliged to halt, is limited at the present time to a consideration of the peak noise levels, which depend to a large extent on the effects of starting the vehicles, and on the L_{eq} values which can be quite large as a result of the slowing down of lorries. The length of the zone of influence of an intersection increases with the cruising speed of the vehicles over the range of 0 to 60 km/h. It should be noted that at higher cruising speeds (80 to 100 km/h) the noise due to the halting of vehicles is not so troublesome, at least so far as the zone upstream of the intersection is concerned.

In the case of one-way streets, the presence of traffic lights gives rise to an L_{eq} value downstream which is greater than that upstream from the intersection. The difference between the downstream and upstream values can amount to as much as 10 dB(A) where the traffic does not include many heavy vehicles and providing that the streets are not too narrow with high buildings to each side. Thus people living upstream are in a favourable position in this situation and this factor can sometimes influence the decision that is taken with regard to the direction to be followed by the one-way traffic (e.g. such that vehicles will be accelerating and not brought to a halt on a bridge — unfortunately there is also the problem of atmospheric pollution that needs to be taken into account here).

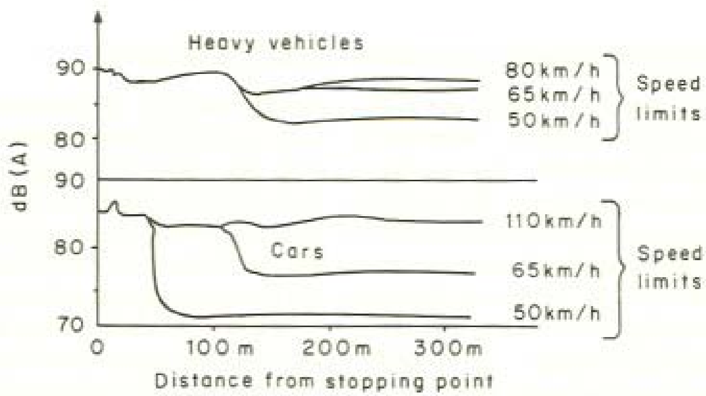


Figure 12.21 Effect of applying different speed limits on the level of noise due to vehicles accelerating away from a halt. (from Raff and Perry 1973)

The following graph shows how the halting of vehicles can lead in particular to an increase in the value of L_{max}, especially in the case of cars. A controlled, green wave, operation of the traffic lights can be an advantage here to the extent that it results in a reduction in the number of times that vehicles are obliged to stop as well as controlling their speed. There can also be an increase in the noise and fuel consumption of the vehicles when there is a gradient at the intersection.

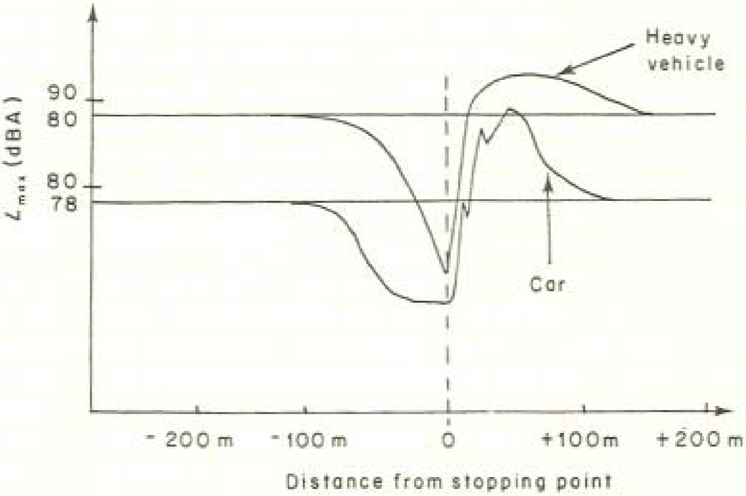


Figure 12.22 Graph illustrating the advantage of eliminating an intersection with regard to the noise from heavy lorries compared with that due to cars

12.6.4 Reduction of Noise Levels on Partitioning Town Centres

The partitioning of limited areas has been followed by application of the technique on the scale of a complete town, e.g. at Gothenburg in Sweden and Groningen in Holland. Thus in August 1970, the centre of Gothenburg was divided into five zones on the basis that the boundaries between zones could only be crossed by pedestrians and by public transport or emergency vehicles. Through traffic and traffic between zones was diverted on to a peripherial route (see Figure 12.23). Traffic on the unblocked streets in the centre of the town was reduced by 70% as a result of this measure while the total vehicle-kilometres, including that due to the through traffic, had increased by no more than 7%. There was also a significant reduction in the number of road accidents per year.

The partitioning technique was applied more recently in the case of Groningen in Holland (a town of 160,000 inhabitants). Thus the technique came into operation on the 18 September 1977, the town having been divided into four zones and through traffic diverted onto a peripheral road. Prior to the

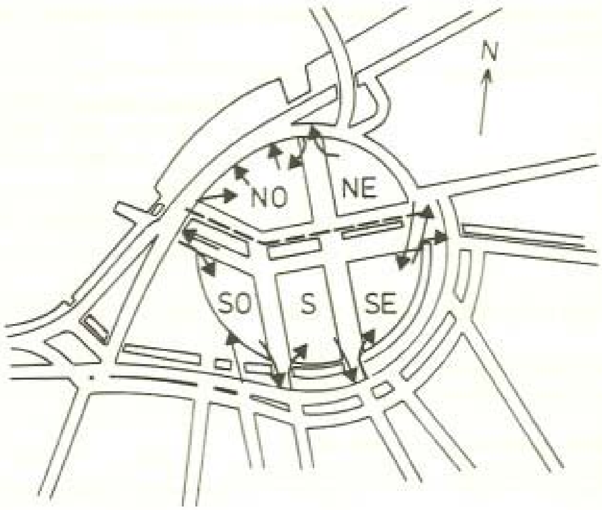


Figure 12.23 Gothenburg (downtown): traffic re-organization principle (1971) (Göteborg OCDE, 1979)

introduction of this measure some 40% of the vehicle-kilometres arising in the centre of the town was due to vehicles for which the town centre was not the destination (Göteborg OCDE, 1979).

12.6.5 Reduction of Noise Levels as a result of Coordinated Actions

The local authority for a town is in a better position than the central government when it comes to co-ordinating a number of actions aimed at reducing the noise due to road traffic, particularly when it is a matter of combining the protection of buildings from noise and the organization of the road traffic. Following the drawing up of a map giving details of the noise levels in the city of Oslo in 1975, the Norwegian government issued a white paper stressing the importance of active traffic control measures rather than passive action such as the provision of noise screens and the sound proofing of building facades. In carrying out a cost effectiveness study a comparison was made between a purely defensive strategy based on the protection from noise and a mixed strategy where the need to provide protection was alleviated by the application of traffic control measures concerned in particular with the circulation of heavy vehicles.

Table 12.8 shows the advantage of applying a mixed strategy—additional advantages are increased safety and reduced atmospheric pollution. It should be noted that in the case of the mixed strategy the cost of applying the traffic

Table 12.8 Cost of alternative strategies aimed at reducing the noise inside buildings to an acceptable level

Strategy	Cost according to different targets for the noise level inside buildings (millions of kroner)		
	35 dB(A)	40 dB(A)	45 dB(A)
Strategy A			
Sound proofing and provision of noise barriers	21.1	14.3	5.3
Strategy B			
Combination of sound proofing, provision of noise barriers and application of traffic control measures	17.3	10.1	4.8
Saving resulting from the application of the combination strategy B rather than strategy A	3.8	4.2	0.5

control measures amounts to only 5% of the capital cost involved in providing protection from the noise.

The municipal authority for Oslo allocated a sum of 0.9 million kroner for the sound proofing of the facades of buildings bordering the roads. The municipal authority decided which buildings should be treated and the individual owners had the option of calling for a higher standard of sound proofing that had been allowed for by the authority on the understanding that the owners would make up the difference in cost. It is considered in Oslo, contrary to the widely accepted view, that sound proofing does not necessarily lead to significant reductions in the consumption of energy for the heating of buildings.

Central government authorities dispose of large sums of money but are not in a position to organize the traffic in individual towns and we might ask if this is why such authorities tend to favour policies based on the sound proofing and protection of buildings from noise rather than the softer options based on a control of the traffic. Given the advantages that can result from a good organization of the traffic, it is to be hoped that municipal authorities will take a stronger line here. The example of New Zealand provides us with an indication of the possibilities. Thus the 1962 Transport Act gave the local authorities the power to restrict the circulation of heavy vehicles with a view to protecting the environment so that transport companies were no longer in a position to demand compensation as a result of any increase in trip lengths, etc. Given this legislation, the town of Auckland was able to improve the conditions in the Parkhill residential area (10 km^2) located between the docks and the industrial zones. This was done in agreement with the transport companies and the measure proved to be very effective on the basis of a very appropriate deviation of the traffic.

12.7 NOISE REGULATIONS CONCERNING THE SOUND-PROOFING OF VEHICLES

12.7.1 Noise Regulations—EEC Requirements

The radiation of noise from road vehicles is the subject of regulations in accordance with national requirements. Generally the maximum acceptable

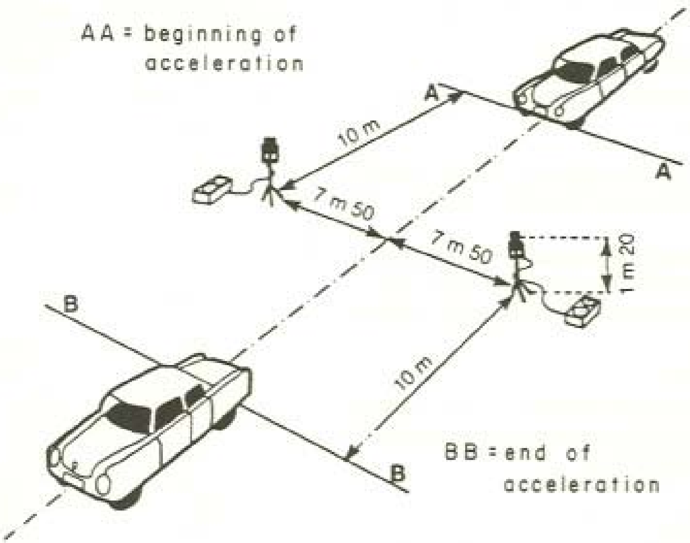


Figure 12.24 Measurements of the noise due to a car

noise levels are specified with respect to precisely defined conditions in the ISO (DP 7188) standard. Thus the noise is measured, as shown by Figure 12.24, on making use of a microphone located at a height of 1.2 metres above ground level and at a distance of 7.5 metres from the centre line followed by the passing vehicle. The vehicle is operated in second and third gear depending on whether it is fitted with a gearbox having four or more ratios and at a speed resulting in maximum power output from the engine. The vehicle must be accelerated at the maximum rate over a distance of 10 metres ahead of the point where it will be immediately opposite the microphone plus 10 metres beyond this same point. The significant noise level is considered to be the maximum level recorded during the passage of the vehicle past the microphone. It should be noted that there are some arguments about the requirements of this standard to the effect that they do not correspond to the type of operation most frequently encountered in practice, (Institute of Transport Economics. Norway 1979).

Table 12.9 gives the noise level limits according the EEC regulations for the different types of vehicles.

Table 12.9 Maximum acceptable noise levels for the new vehicles in the EEC

	Maximum acceptable noise levels (dBA)	
Type of vehicle	According to order dated 13 April 1972 (amended)	According to orders for 1980–1988 (order dated 16 Sept 1977)
Private cars	82	80
Vehicles other than private cars and having a GVW of not more than 3.5 tonnes	84	81
Public passenger transport vehicles having a GVW of more than 3.5 tonnes and not belonging to any of the categories listed below		
—Buses	89	82
—Coaches	89	84
Public passenger transport vehicles fitted with engines having an output power equal to or more than 200 h.p.		
—Buses	91	85
—Coaches	91	87
Commercial vehicles having a GVW of more than 12 tonnes and fitted with engines having an output power equal to or more than 200 h.p.	91	88
Commercial vehicles having a GVW of more than 3.5 tonnes and not belonging to the above mentioned category	89	86
Two-wheeled vehicles		
—Mopeds (in France)	72	
—Light motorcycles	80	
—Motorcycles	84	
Vehicles having more than two wheels		
—Motorcycles	73	
—Powered tricycles and quadricycles	81	

12.7.2 Sound-Proofing of the Vehicles

The noise emitted by the vehicles can be reduced on taking action at three different levels defined in terms of the period of time likely to be taken in achieving practical results:

A. Level 1—Short Term

This is a matter of reducing the noise emitted by existing designs of vehicle by a more or less complete enclosure of the engine and transmission, on making more effective use of the volume of silencers or on increasing this volume, by fitting different tyres, etc. In the case of vehicles that are already in use, these modifications are only being applied to buses.

B. Level 2—Medium Term

This level of action is concerned with new designs of vehicle but without involving any fundamental changes in the manufacture of the more important parts of the vehicle: use of quiet and low-speed engines, modification to the drive axle gear ratios, modifications to engine accessories such as rocker-arm covers, sump cases, etc.

C. Level 3—Long Term

This is a matter of considering a complete redesign of the vehicle subsystems and components and in particular of the engine, the engine accessories and the complete cooling system.

Reductions in the emission of noise, under the conditions called for by the ISO standard, as a result of action at Levels 1, 2 and 3, could amount very approximately to 3, 6 and 10 dB(A) respectively. Action at the first two levels has already been followed by commercial production but action at the third level has only proceeded so far as the development of prototypes of heavy vehicles that are not likely to be available as production vehicles before 1990.

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