Proceedings of The Institute of Acoustics

OPTIMAL DESIGN OF HIGHWAY NOISE BARRIERS

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INTRODUCTION

Appraisal of the noise impact of trunk road schemes is now a standard part of the highway design process which must include both the social and financial effects of noise [1]. It is no longer adequate for noise control to be a post hoc consideration limited to a few, expensive lengths of panel fencing and blanket noise insulation of dwellings. Recent experience shows a public preference for highway barriers rather than noise insulation, despite the fact that they give relatively small improvements in noise levels.

Correct route selection is important in controlling noise impact, although other considerations are generally uppermost at that stage, whilst at the design stage, although limited in scope, correct horizontal and vertical alignment is of crucial importance.

Hitherto, it has been difficult to assess these effects in sufficient detail and in sufficient time to feed them back into the route selection or design process (a fact which may be implicit in the rather crude noise assessment procedure for Public Consultation [2]), although recent developments in noise calculation techniques have made this much easier [3, 4].

The purpose of the noise engineer in making variations of the vertical alignment is to use the barrier screening effect and hence the problem of noise control at the design stage may be considered largely to be the optimal design of highway noise barriers.

THE PERFORMANCE OF LONG BARRIERS

To gain an insight into the practical performance of a long noise barrier, Figure 1 shows the noise level attained at a first floor receiver at various distances behind noise barriers of a number of heights. It is based on a typical motorway traffic flow of 80,000 veh/hr, 15% heavy vehicles at a mean speed of 108 km/hr, with a Basic Noise Level of 82.7 dB(A) L_{10} (18-Hour) and was derived from "Calculation of Road Traffic Noise" (CRTN) [3]. It is only strictly applicable where the receiver is 5m above road level, although it may be used as an indicator in other cases provided the receiver is distant from the road. It relates to an infinite length of road; but may be adjusted for practical lengths, if necessary, by reducing the receiver noise level according to the angle, A degrees, subtended at the receiver using the formula:-

$$\text{angle correction} = 10 \log \left(\frac{A}{180}\right) \qquad (1)$$

or using the equivalent chart 10 in CRTN.

Talking in round figures, it can be seen, for example, that a receiver 100m from the carriageway would require a barrier 2m high if statutory insulation is to be avoided, i.e. a noise level of less than 67.5 dB(A) L10 (18-hour) [5]. At 50m from the road, the barrier would have to be 3.5m high and at 20m from the road, 5.5m high. To meet a more stringent target such as 65 dB(A), a

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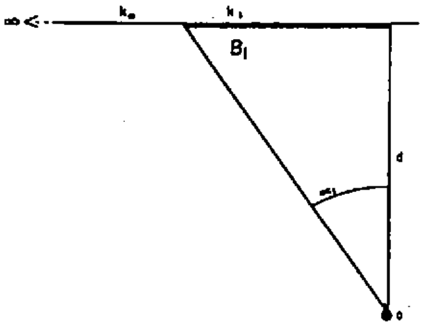
noise barrier would be required to protect receivers as distant as 300m (the limit of validity of the calculation method).

Figure 1 can be used with other traffic flows. Calculate the Basic Noise Level of the flow, find the difference between the desired target (receiver) noise level and this Basic Noise Level and use this difference to enter the chart via the scale on its right-hand side. For example, for a Basic Noise Level of 80 dB(A) and a target (receiver) noise level of 60 dB(A), enter the chart at -20 on the RHS. This shows, for example, that a barrier at least 2.5m high would be necessary to protect a receiver 200m from the road.

Clearly, it would be possible and cheaper to achieve the same target with a shorter length of higher barrier, since an infinitely long barrier is infinitely expensive. To find an optimal solution, it is necessary to consider how noise levels and costs vary with barrier height and length.

LENGTH OF BARRIER NEEDED TO SCREEN A ROAD



Let l_0 be the sound level (dB) produced at a receiver O at a distance, d, from an infinite length of unscreened road. Therefore, the corresponding sound intensity is $k_0 = 10^{(l_0/10)}$.

Let l_1 and k_1 be the sound level and corresponding intensity produced at receiver O by a barrier B1 of infinite length which screens the road.

Consider the half-space to the left of O (see Figure) and suppose that when B1 subtends the angle α_1 degrees at the receiver, the desired sound intensity, K, is achieved, corresponding to a desired sound level $L = 10^{(K/10)}$.

The respective sound intensities at O from the screened and unscreened parts of the road is proportional to the angles which they subtend and hence:-

$$(90-\alpha_1)p.k_0 + \alpha_1.p.k_1 = K \text{ (where p is a constant of proportionality)}$$

$$\text{or } 90.p.k_0 + (k_1-k_0)p.\alpha_1 = K$$

from which, Angle subtended by barrier, $\alpha_1 = \dfrac{K-90.p.k_0}{p(k_1-k_0)}$ ....(2)

By trigonometric definition,

The length of the barrier, $B_1 = d\text{-}\tan\alpha_1$ ....(3)

The constant of proportionality, p, can be chosen as 90 or 180 degrees^{-1}.

When p = 180, α_1 will be the angle at which the desired intensity is met by sound radiated from the half-space. This is a useful formulation when the component from the right-hand half-space is known separately.

When p = 90, α_1, is the angle at which the desired intensity is met by sound radiated from the whole space symmetrical about 0, i.e. there is an equal contribution from the right-hand half-space.

Note that where the actual angle subtended by the road in the half-space is less than 90 degrees (i.e. the road is not infinitely long) equation (2) can be still used if the constant 90 is amended to equal the actual subtense.

BARRIER COSTS

Barrier costs cannot be quantified precisely. In some cases, noise bunds can be constructed from surplus material and this may provide a cost saving in the disposal of the material. In other cases, the vertical alighment might be adjusted to provide the required material. This paper, however, is based on recent costs for heavy close-boarded timber fences as shown in Table 1.

Table 1 : Typical Cost Of Heavy Close-Boarded Timber Noise Barrier

Height (m)	Cost Range (£/Linear Metre)	Median Cost (£/Linear Metre)
2	50-80	65
2.5	60-90	75
3	90	90

In some cases there may be additional costs such as the provision of safety fencing, (costing some £20/Linear Metre) but these are not considered here. Data is not available for lower barriers (which are not generally acoustically effective on their own, see Figure 1), nor for higher barriers, for which it is usually preferred to construct the lower part from an earth embankment. Because of extra wind loading, higher barriers require stronger posts, rails and foundations, and it can be postulated that these would lead to a square-law dependence of cost, Figure 2, which fits the scanty data available.

OPTIMAL BARRIER HEIGHT

From equations (1) and (2), and using the noise levels shown in Figure 1, it is possible to construct a family of curves for various receiver distances showing the half-space angle required by barriers of different heights to meet a desired target level, Figure 3 shows the angle required to meet a criterion of 64.4 dB(A) L10 (18-hour), (i.e. a criterion of 67.4 dB(A) if the other half-space makes an equal contribution).

The corresponding barrier lengths are shown in Figure 4. As the barrier height increases, the required barrier length at first decreases rapidly, but then asymptotes to a minimum value, with little reduction in length for successive height increments. Because the higher barriers are more expensive, however, this results in a minimum in the corresponding cost curves, Figure 5. In this example, the cost minima are at the barrier heights shown in Table 2.

Table 2 : Minimum Cost Barriers

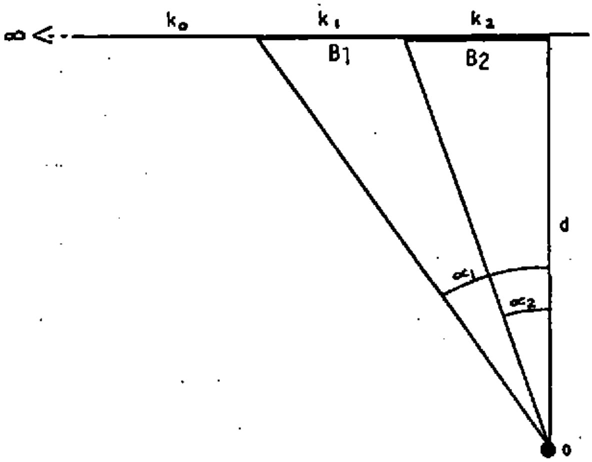
Receiver Distance (m)	Barrier Height (m)	Noise Level From Infinitely-Long Barrier dB(A)
80	3.7	64.4
100	3.2	64.2
120	3.0	63.9
150	2.5	64.0

Looking at the noise level expected behind infinitely-long barriers of these heights, Table 2, they fall in the range 3.0-3.4 dB(A) below the target level of 67.4. However, this cannot be regarded as an absolute rule as it is dependent on the relative costs of the various heights of barrier. This is discussed in more detail below.

As Figure 5 shows, the cost saving of using the precise optimum relative to the nearest equivalent standard height could be considerable, but in practice, contractors are likely to charge 'over the odds' for such custom heights.

COMBINATION OF BARRIERS OF DIFFERENT HEIGHTS

It is possible to tailor lengths of noise barrier of two or more different heights to achieve a target noise level, as shown in the diagram below.



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It can be shown that target level L, giving rise to target intensity $K = 10^{(L/10)}$ is given by the relationship

$$90.p.k_o + \alpha_1 p(k_1-k_o) + \alpha_2 p(k_2-k_1) = K \qquad \text{............(4)}$$

and the cost C is given by:

$$c_1 d.\tan \alpha_1 + (c_2-c_1)d.\tan \alpha_2 = C \qquad \text{............(5)}$$

where k_o, k_1, k_2 are the sound intensities corresponding to the sound levels l_o, l_1, l_2 ($l_o > l_1 > l_2$) found at distance d when the whole road is screened by no barrier, barrier 1 and barrier 2 respectively; and c_1 and c_2 are the costs per linear metre of barriers 1 and 2 respectively.

Equation (4) may be extended to cope with more barriers by adding terms of the form $\alpha_i p(k_i-k_{i-1})$, and equation (5) may be extended analogously.

$$\text{From (4)} \quad \alpha_1 = \frac{K-90p.k_o}{p(k_1-k_o)} - \alpha_2\frac{(k_2-k_1)}{(k_1-k_o)} \qquad \text{................(6)}$$

$$\text{or} \quad \alpha_2 = \frac{K-90p.k_o}{p(k_2-k_1)} - \alpha_1\frac{(k_1-k_o)}{(k_2-k_1)} \qquad \text{................(7)}$$

These equations hold for $0 \leq \alpha_1 \leq 90$, $0 \leq \alpha_2 \leq \alpha_1$, otherwise there is no solution. They degenerate to the single-barrier cases when $\alpha_2 = 0$ and $\alpha_1 = \alpha_2$.

Although it is possible to write a relationship for the values of α_1, α_2 to give the minimum cost solution, an analytical solution is difficult to obtain.

An alternative approach is to evaluate (4) and (5) to obtain a range of solutions with the corresponding cost. It is evident that the more economic solution is given when B_2 is the higher of the two barriers, since the intensity-reduction is proportional to α whilst the cost is proportional to $\tan \alpha$.

Figure 6 shows the effect of a range of 2-m and 3-m barrier combinations, for two different costs of 2-m barrier designed to a half-space level of 64.4 dB(A). The greater cost is the median £65/metre and the smaller cost is £50/metre. The 3-m barrier is taken to cost £90/metre in both cases. The range of solutions varies from screening solely by 3-m barrier, through a combination of the two heights, to screening solely by 2-m barrier (where such a solution is possible). The single height cases are indicated by dotted curves.

The minimum cost solution is very price-sensitive: for example, it would be £2,000 cheaper to screen a 150-m distance receiver with 2m barrier rather than 3m barrier, if the former can be obtained at £50/metre. For closer receivers, where 2m barrier will not give adequate screening alone, barrier combinations can offer substantial cost savings when the cheaper barrier is available.

GENERAL RULES FOR OPTIMAL BARRIER DESIGN

Work is in progress to formulate and test a set of general rules for optimal barrier design. Initial indications are that the following should be considered. Clearly, manual application of these rules will be cumbersome, but it is expected that in conjunction with a modelling suite such as ROPLAN [4], a practical computer application can be developed.

For Straight Roads

(a) If cost is not a factor, the location of barriers can be derived by evaluating (4), if necessary with additional terms added as described to include any existing lengths of screening.

(b) If cost is a factor, higher barriers should start at the perpendicular from the receiver and extend towards wider angles of screening until the desired target level is achieved.

(c) Barrier heights are governed by a number of external factors - cost, space (if a bund), visual amenity, etc. Acoustically, they should be sufficient to be reasonably effective, e.g. having a potential to reduce the noise level some 3 dB(A) below design target on an infinitely long road.

(d) The left and right half-spaces should be dealt with separately. Aim to make their contributions equal, unless natural screening already causes one to give 3 dB(A) or more below target.

For Other Roads

(e) These should be considered as a number of n straight segments, each dealt with separately. Aim to make their contributions equal, using rules (a), (b), (c) unless natural screening, distance, etc already makes some contributions 10 log n dB(A) or more below target. In such cases, it is permissible to allow the other segments to contribute correspondingly more noise.

CONCLUSION

By using the given formulae, it is possible to calculate the required length, or combinations of length, of barriers of various heights to meet a design noise level. A set of design rules are suggested to assist in practical application of the formulae. Depending on barrier prices, a combination of barrier heights may give the cheapest solution.

In practice, even with the assistance of these rules it would be cumbersome to find an optimal design by hand but by linking these in a computer program to a traffic noise modelling suite such as ROPLAN, it is anticipated that a powerful design tool will result. Notwithstanding the designer's professional duty to minimise the noise impact of a highway scheme, the potential cost savings are sufficiently large to make this a worthwhile objective.

REFERENCES

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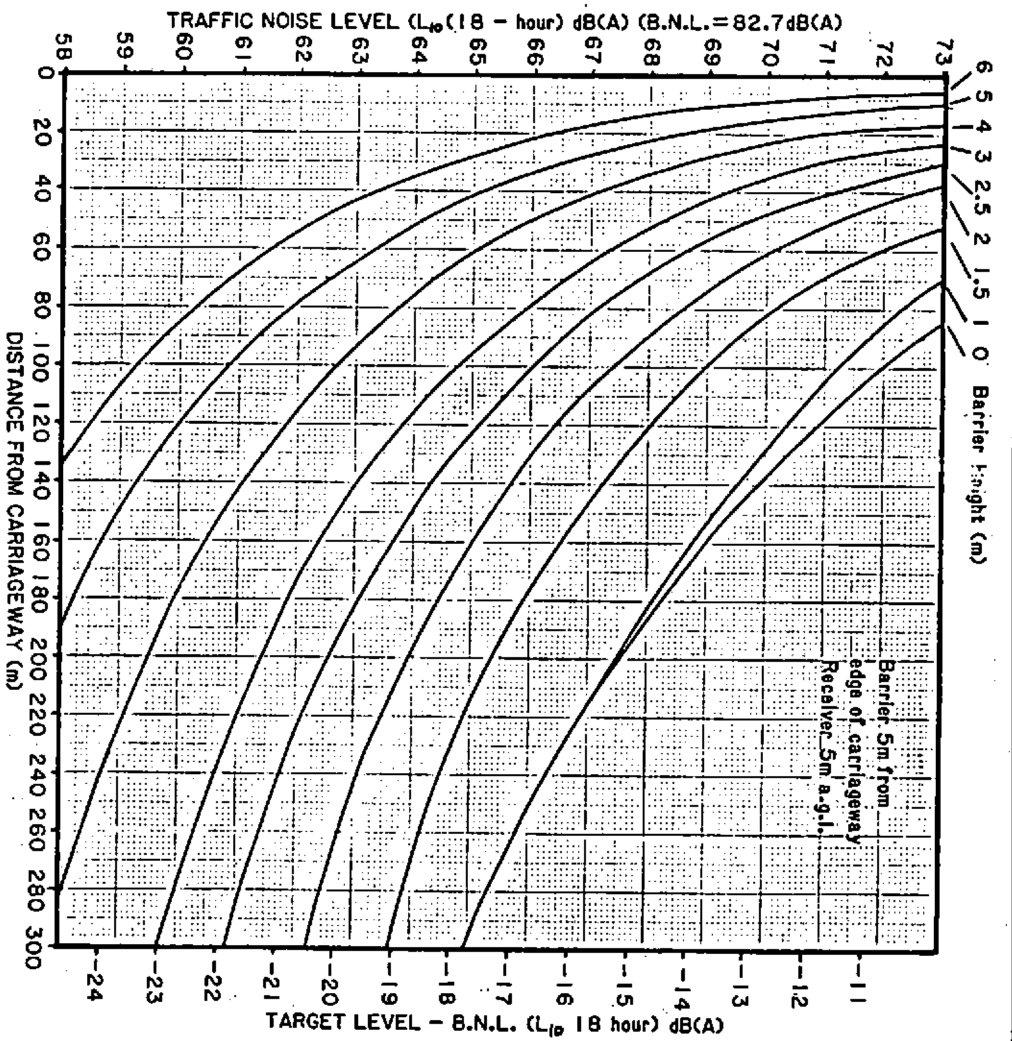
[2] 'Manual of Environmental Appraisal'. Department of Transport 1983.

[3] 'Calculation of Road Traffic Noise'. Department of the Environment Technical Memorandum. HMSO 1975.

[4] K R Tompsett. 'ROPLAN - Software for modelling noise from road schemes'. Proc. IOA Vol 7 Part 2 355-359 (1985).

[5] Building and Buildings. The Noise Insulation Regulations 1975. Statutory Instrument 1975 No. 1763.

Figure 1



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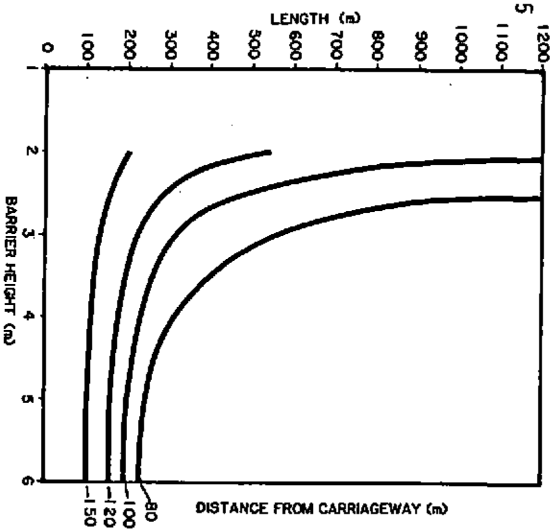

Figure 5

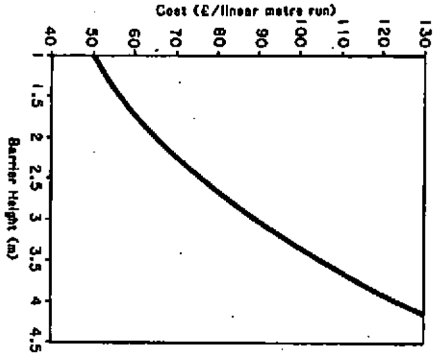

Figure 2

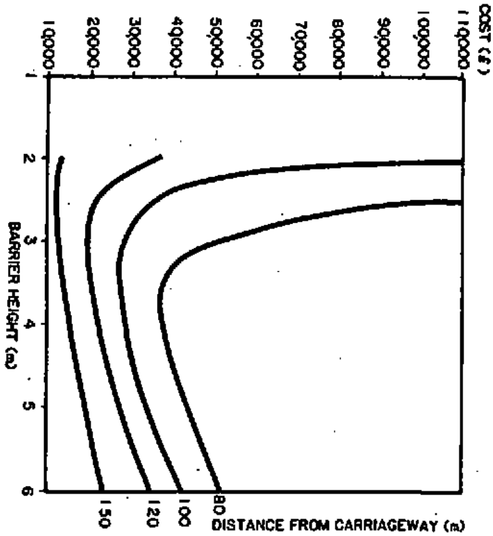

Figure 4

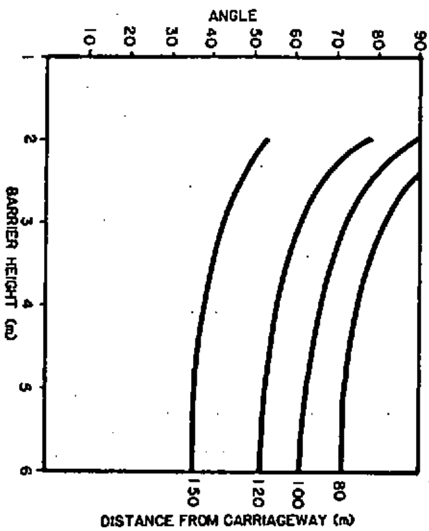

Figure 3

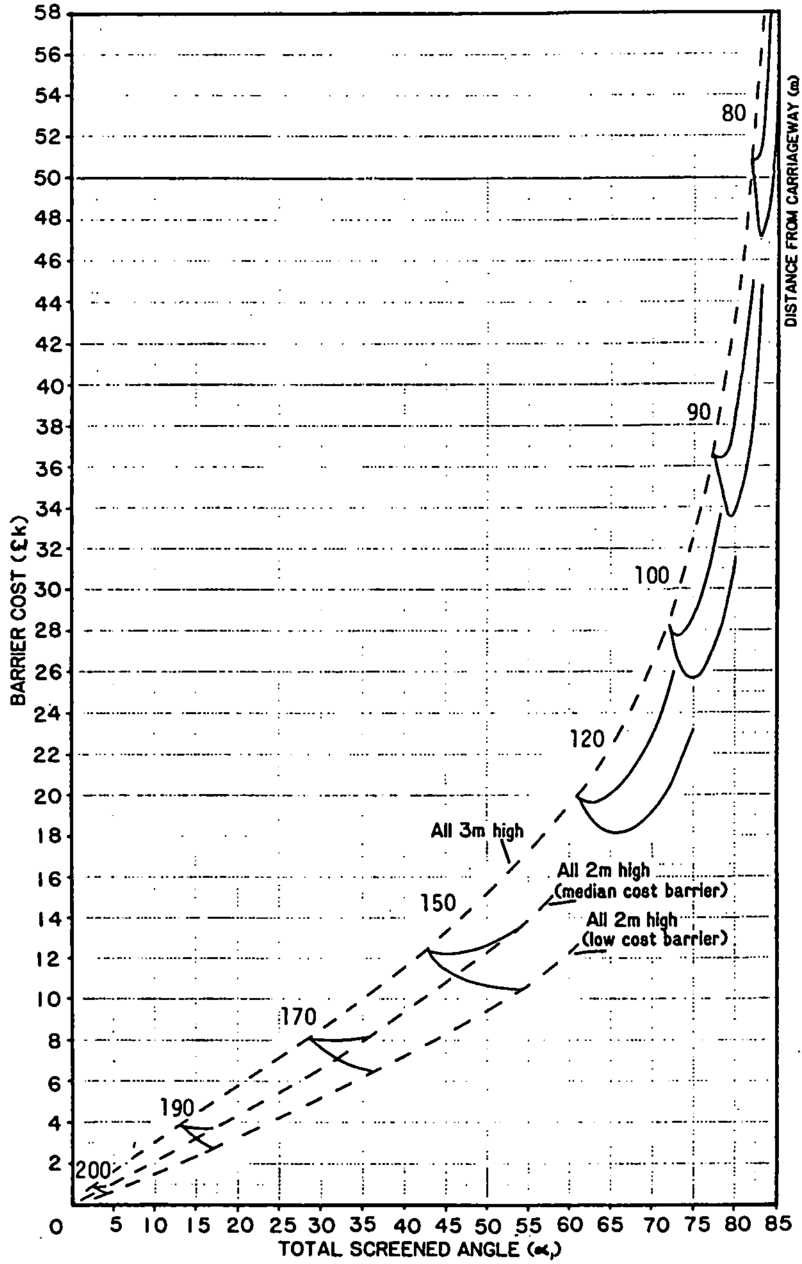
BARRIER COST (£k)
TOTAL SCREENED ANGLE (α)
DISTANCE FROM CARRIAGEWAY (m)
All 3m high
All 2m high (median cost barrier)
All 2m high (low cost barrier)
80
90
100
120
150
170
190
200

Figure 6