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NUMERICAL MODELLING OF MEDIAN ROAD TRAFFIC NOISE BARRIERS

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Outdoor sound propagation from road traffic is modelled by solving a boundary integral equation formulation of the wave equation using boundary element techniques in two dimensions. In the first model, the source representing a traffic stream can be considered as a coherent line source of sound. The results can then be transformed to derive a pseudo-three dimensional solution to the problem. In the second model the line source is incoherent. For receivers near the ground, the second model predicted significantly higher values of ground attenuation than the first. The first model generally produced better agreement with ground attenuation results obtained using the U.K. traffic noise prediction model. For conditions when a noise barrier was present and the ground was absorbent, the incoherent line source model generally predicted significantly higher values of attenuation than those from the barrier and ground attenuation calculated separately. Over a range of receiver positions and barrier heights a similar, but less marked effect was observed when the coherent line source model was used. On dual carriageway roads, it is possible to incorporate barriers on the central reservation as a noise control measure. These are "median" noise barriers. The incoherent line source model is used to assess the performance of median barriers in reducing noise when installed alone and also with associated roadside barriers. A sound absorbent median noise barrier 1 m in height produced consistent values of insertion loss of between 1 and 2 dB over the range of receiver positions and ground conditions considered. When the median barrier was used in conjunction with a roadside barrier it produced a consistent improvement in insertion loss of between 1 and 2 dB over the range of conditions considered.

1. INTRODUCTION

Outdoor sound propagation from road traffic can be modelled by solving a boundary integral equation formulation of the wave equation using boundary element techniques in two dimensions. The results can then be transformed to derive a pseudo-three-dimensional (3-D) solution to the problem. In the first case, the source representing a traffic stream can be considered as a coherent line source of sound and in the second case the line source is incoherent.

The results for sound propagation above ground planes which are rigid and have finite impedance appropriate to grassland are calculated using the coherent and incoherent line source models and are compared with those from a standard prediction method for road traffic noise [1]. This method was derived from extensive site measurements and has been used in the paper to provide an indication of realistic average experimental results.

In most standard outdoor noise propagation models, e.g., those of references [1, 2], the sound attenuation associated with the propagation over ground of finite impedance (grassland) can be calculated as a correction term. The ground attenuation term is

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dependent on the mean height of propagation above the surface. When a noise barrier is introduced, a correction term for the attenuation of the noise barrier can be calculated based on the path difference between the length of the direct ray from the source to the receiver and the rays via the upper edge of the barrier. Both standards specify that when there are both finite impedance ground and a noise barrier at a site, the corrections for each effect should be calculated and only the greater of the two applied. In many cases where the receiver is in the shadow zone of the barrier and at short or medium range, the barrier attenuation will predominate. Both standards indicate that when the two corrections have similar values, some combination of the two attenuation effects will be expected but this is not quantified. By using the models to calculate the attenuation of a barrier when the ground is rigid and then when the ground is grassland the extra attenuation that is produced by grassland will be estimated.

On dual carriageway roads, it is possible to incorporate barriers on the central reservation as a noise control measure. We will term these as "median" noise barriers. Space is usually available to construct such barriers, which may require protection by the usual vehicle crash barriers. Passenger vehicles travelling at high speed generally occupy the lanes closest to these barriers. For such vehicles, the main source of noise is the tyres. A commonly proposed design for such barriers is that they should be low, say 1 m in height, and have surfaces that are capable of absorbing sound. This design may be argued to be efficient since the major sound source is close to the ground and close to the barrier. Some interruption of sight between the two carriageways is desirable for many road configurations and median barriers also fulfil this requirement.

Median barriers have been proposed by other workers. Watts [3] considered the possibility of median barriers placed two parallel roadside barriers separated by a distance of 34 m. Experiments were undertaken at the Noise Barrier Test Facility at the Transport Research Laboratory where the source was placed 0·5 m above an asphalt surface, 7·8 m in front of the nearside barrier. Receiver locations were 20, 40 and 80 m behind the nearside barrier and at heights of 1·5 and 4·5 m. Comparisons were made with a 2 m single, reflective barrier. Results suggested that with a median barrier of height 1·25 m screening improved, with noise levels of 1 dB lower than with a single, reflective 2 m barrier. Results were also compared with results from a boundary element model using coherent line sources.

The incoherent line source model is used to assess the performance of median barriers in reducing noise when installed alone and with associated roadside barriers.

2. NUMERICAL MODELS

The 2-D problem is considered in a vertical plane perpendicular to the barrier and the parallel source lines. The wave equation, expressed as a boundary integral equation, is solved by using standard boundary element methods. This approach allows great flexibility in the specification of the shape, position and surface impedance of the barriers, the characteristics of the ground surface and the source positions. The solution has been described before [4] and is equivalent to that for a 3-D system with barriers of uniform characteristics along their length and coherent line sources of sound. To avoid problems, which may arise from singularities in the solution at frequencies, which correspond to the eigenfrequencies of the interior domain of the system a formulation of the integral equation of the type proposed by Burton and Miller [5] was used.

This solution as a function of frequency can be transformed into a pseudo-3-D solution appropriate for an incoherent line source by using the integral transformation given by Duhamel [6]. In the calculation reported here the infinite integral (equation (10) in reference

TABLE 1

Parameters used for the calculation of surface impedance

Material	Flow resistivity (N s/m^4)	Layer depth (m)
Grassland	350 000	Infinite
Sound-absorbing barrier surfaces (median barrier)	20 000	0·1

[6]) was approximated by integration limits of ± k, where k is the wavenumber. Only the real parts of the integral were used.

The derivation of the boundary integral equation in the form used depends on the assumption that surfaces of finite impedance are locally reacting. A simple and well-established model [7] that can be adapted to allow for a hard-backed layer of absorbent material was used to define the impedance of the surfaces. The parameters used in the model for grassland and a typical sound absorbing barrier surface are shown in Table 1. An unperturbed Green function for propagation above a uniform boundary with impedance typical of grassland is used. The sections of rigid surface corresponding to the road are included as part of the discretized perturbation surface which also includes the barrier.

Comparisons were made with results of Jean *et al.* [8], who used a similar approach to that in the current model but with some differences in formulation. In the code of Jean *et al.*, integration was carried out over the whole complex domain. In the current code, pressure is calculated at the centre of each boundary element and is assumed to be constant over the element, unlike the formulation of Jean *et al.*, in which a quadratic approximation is employed to describe the pressure change across each element. It is probable that other significant differences in coding exist. For the comparison, a 4 m high T-shaped barrier with a 1 m wide cap covered with an absorbent surface of flow resistivity 30 000 N s/m^4 was considered, with four incoherent line sources positioned at 4·25, 7·75, 14·25 and 17·75 m to the left of the barrier on the ground. One receiver position was considered at 40 m to the right of the barrier at a height of 5 m. The ground surface in the first case was all grassland ($\sigma = 300\,000$ N s/m^4) and in the second case mixed, with rigid ground on the source side of the barrier and grassland on the opposite side. The comparisons of insertion loss are shown in Figure 1(a) and 1(b). It can be seen that the two sets of results compare very well at the higher frequencies. It has not been possible to identify the source of the discrepancy at low frequencies but this is probably attributable to differences in the implementation of the method.

The results from the numerical model were compared with those of Isei *et al.* [9], who used a different approach. They predicted values of excess attenuation for a barrier on grassland for a line of closely spaced (incoherent) point sources. The MacDonald approximation [10] was used to calculate the diffraction of sound at the edge of the barrier. The site configuration is shown in Figure 2. There is rigid ground on the source side of the barrier and grassland on the opposite side. Excess attenuation spectra are shown in Figure 2. There is some similarity in the results. The model of Isei *et al.* produces consistently higher values, but in a later paper [11] some doubt is cast on the accuracy of their approach.

The numerical solution was calculated at one-ninth octave centre frequencies for the coherent source model and averaged over one-third octave bands. For the incoherent model, calculations were carried out at one-third octave centre frequencies between 50 and

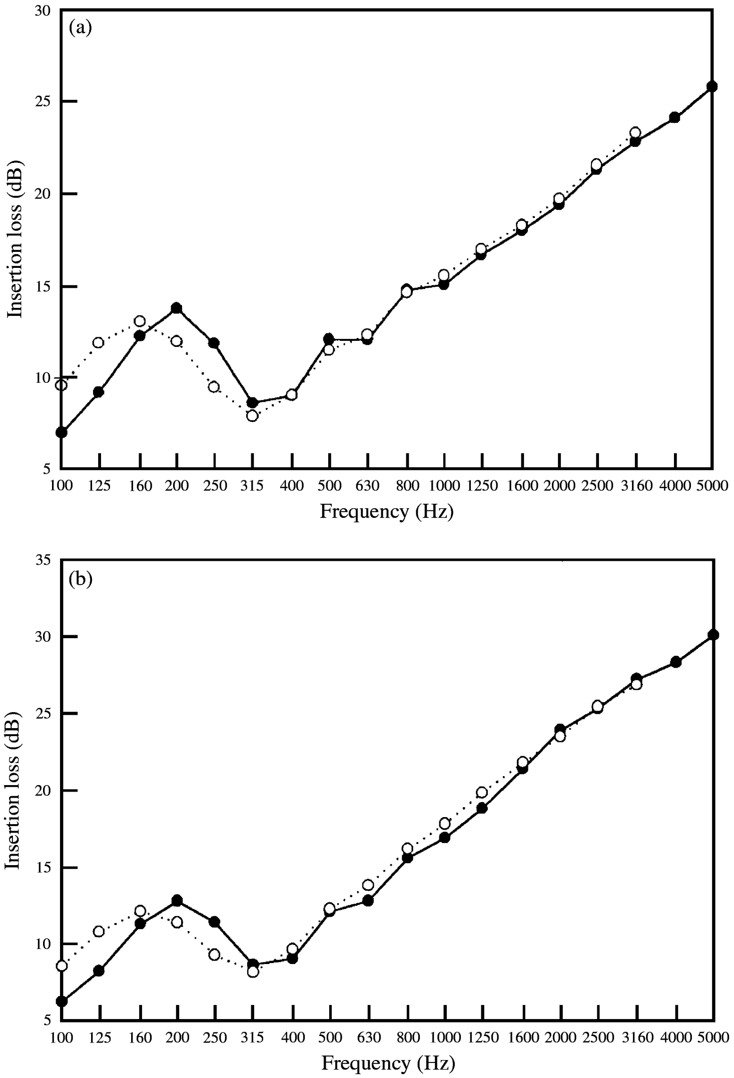

Figure 1. Spectrum of insertion loss for a 4 m T-shaped barrier calculated in reference [8], —●—; and using the incoherent line source model, ········○·········. (a), Grassland; (b), mixed ground.

4000 Hz. In order to simulate a broadband road traffic noise source, the spectrum was weighted using the BS EN 1793-3 : 1998 standard function [12] and then added to derive the broadband *SPL*. From this the insertion loss was determined.

3. RESULTS

The basic site conditions are shown in Figure 3. These simulate a dual three-lane motorway with 3·5 m wide lanes. Six sources were positioned at a height of 0·5 m and in the centre of each lane at 6·25, 9·75, 13·25, 18·75, 22·25 and 25·75 m from the roadside barrier. The road surface and the surface of the roadside barrier were assumed to be rigid. A 1 m grass verge, 3·5 m hard shoulder and 2 m grass central reservation were also included. The

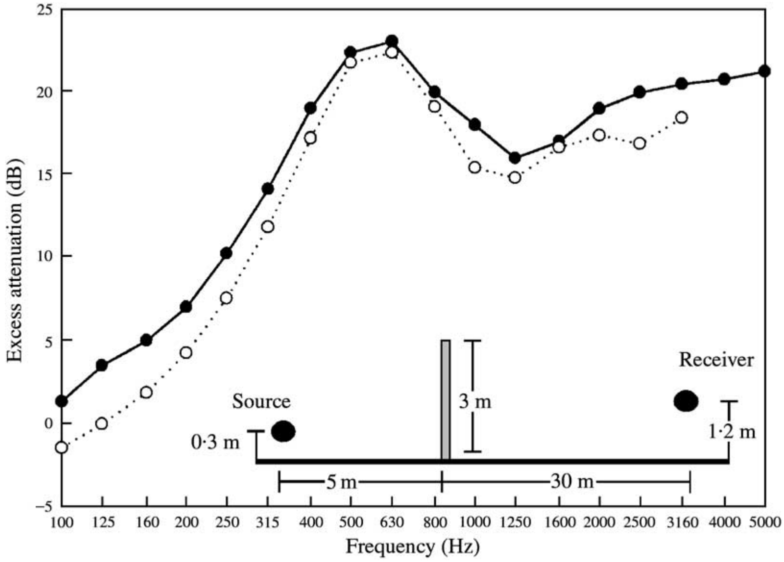

Figure 2. Spectrum of excess attenuation calculated in reference [9], —●—; and by using the incoherent line source model ····○····; for the configuration shown.

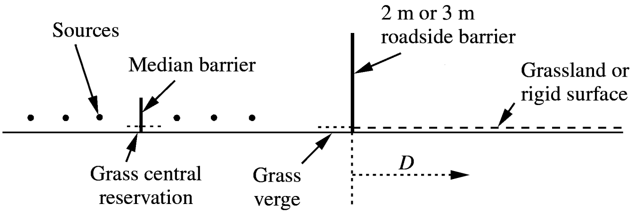

Figure 3. Configuration of the site, which is modelled.

ground behind the roadside barrier was either rigid ground or grassland. Receivers are defined by height above the flat ground and distance *D* from the roadside barrier position.

3.1. UNSHIELDED PROPAGATION

Initially, calculations were carried out for grassland and rigid ground with no barriers present using the incoherent line source model. Figure 4(a) shows the excess attenuation for rigid ground defined as the sound level relative to freefield propagation. The peak in the curve for the 7·5 m receiver height is a result of interference between the direct and ground reflected rays. As distance from the barrier increases, this is eliminated. The excess attenuation converges to approximately −5 dB with increasing distance for receiver heights greater than zero and is constant at −5 dB when the receiver is in the ground. A theoretical value of −6 dB would be expected for rigid ground. The discrepancy is a result of the presence of the grass verge and central reservation. Further calculations without these grass sections produced convergence to −6 dB. In the case of grassland (Figure 4(b)), excess attenuation increases with distance from the barrier as expected.

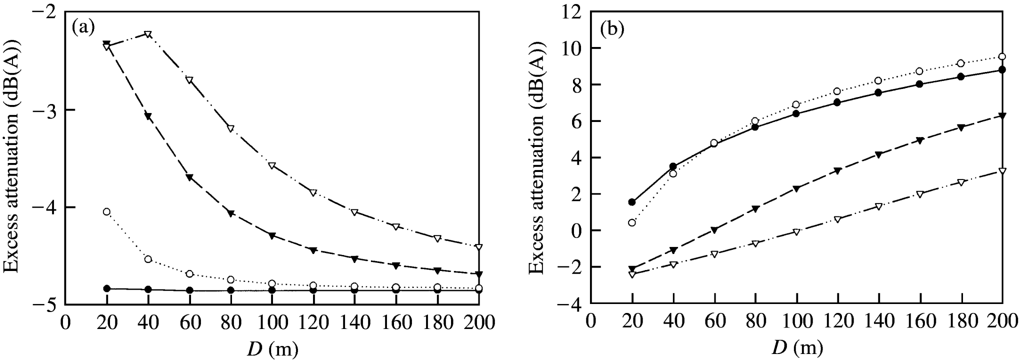

Figure 4. Excess attenuation for conditions without barriers. Numerical model results for incoherent line sources. Receiver height —●—, 0 m; ·····○·····, 1·5 m; —▼—, 4·5 m; —▽—, 7·5 m; (a), Rigid ground; (b), grassland.

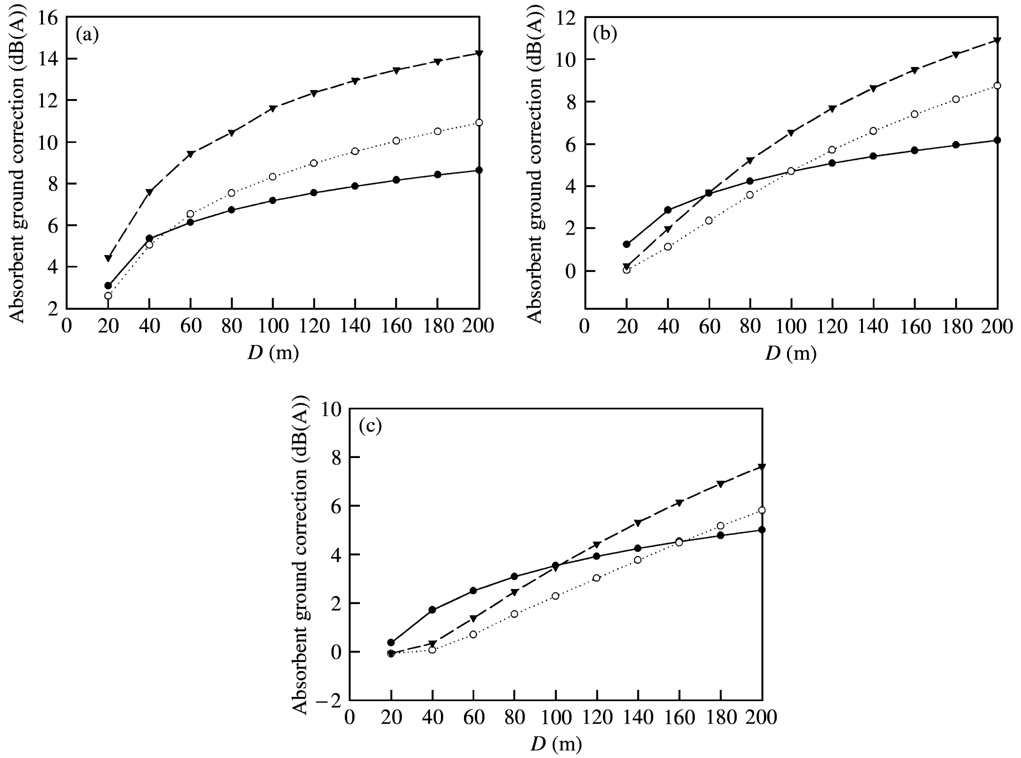

Figure 5. Absorbent ground correction calculated by using ·····○·····, the coherent line source model; —▼—, incoherent line source model; —●—, standard prediction method [1]. Receiver heights in (a), (b) and (c) are 1·5, 4·5 and 7·5 m respectively.

The difference in the results for rigid ground and grassland provides an estimate of the attenuation attributable to the absorbent ground. A correction for this attenuation is given in the Calculation of Road Traffic Noise [1]. The ground attenuation as a function of D is given in Figure 5(a–c) for receiver heights of 1·5, 4·5, and 7·5 m respectively. The standard correction was calculated by using a single source line 0·5 m above the carriageway and

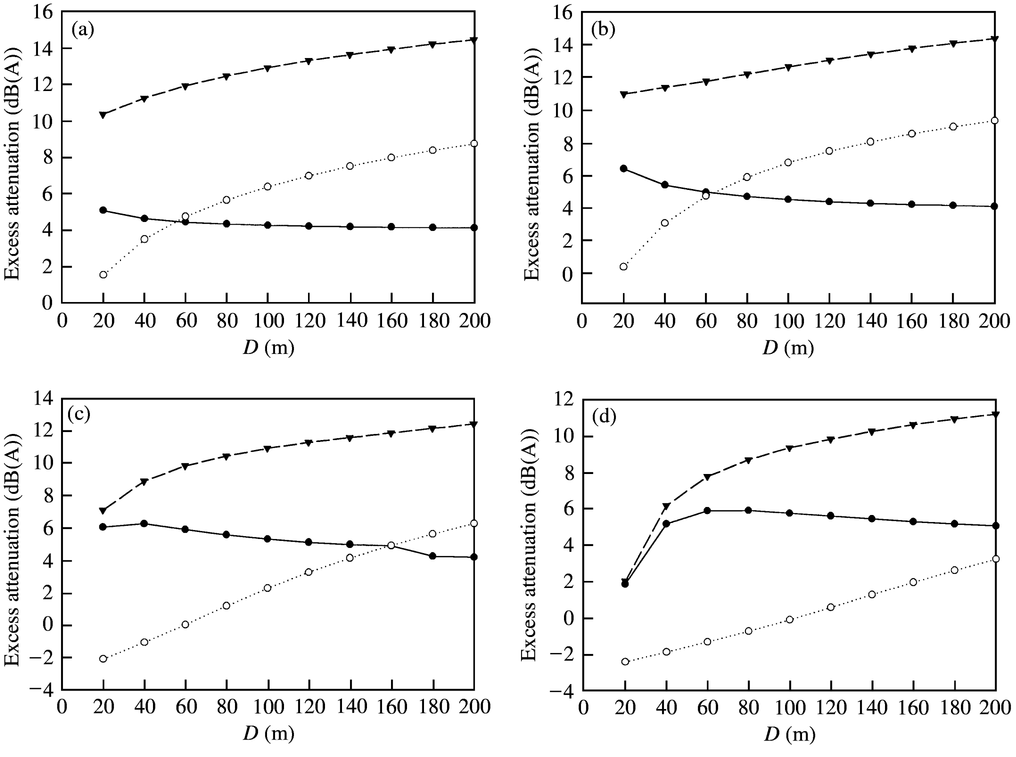

Figure 6. Excess attenuation for unshielded propagation over grassland, ·····○·····, and for a roadside barrier 3 m in height with grassland, —▼— and rigid ground, —●— behind the barrier. Receiver heights are 0, 1·5, 4·5 and 7·5 m in (a), (b), (c) and (d) respectively. Incoherent line source model.

3·5 m from the nearside edge, as required. For a receiver height of 1·5 m, the results from the incoherent line source model are higher than the CRTN values by 1 dB when $D = 20$ m and 6 dB when $D = 200$ m. As receiver height increases the difference in the results is reduced. The calculations were repeated by using the coherent line source model and the results are also shown in Figure 5(a–c). In this case, the agreement with the results of the standard method is better for the lower receiver heights.

3.2. PROPAGATION OVER RIGID GROUND AND GRASSLAND WITH A ROADSIDE BARRIER

All the roadside barriers considered were plane screens with rigid surfaces. Calculations of excess attenuation were undertaken for barrier heights of 2, 3, 4, 5 and 8 m, with either rigid ground or grassland between the barrier and the receiver positions, using the incoherent line source model. The results are illustrated in Figure 6(a–d) for a barrier height of 3 m and receiver heights of 0, 1·5, 4·5 and 7·5 m. Using the methodology of the standard prediction method [1], the excess attenuation attributable to the grassland and barrier combination is determined by selecting the higher excess attenuation from either the barrier or grassland attenuation curves at a given distance. For low receiver heights these curves cross. At a receiver height of 1·5 m (Figure 6(b)), the crossing point is at $D = 60$ m. Below this distance the barrier attenuation predominates and above this distance the grassland attenuation predominates. The third curve illustrates the combination of these effects as calculated using the incoherent numerical model. At this receiver height, this curve predicts

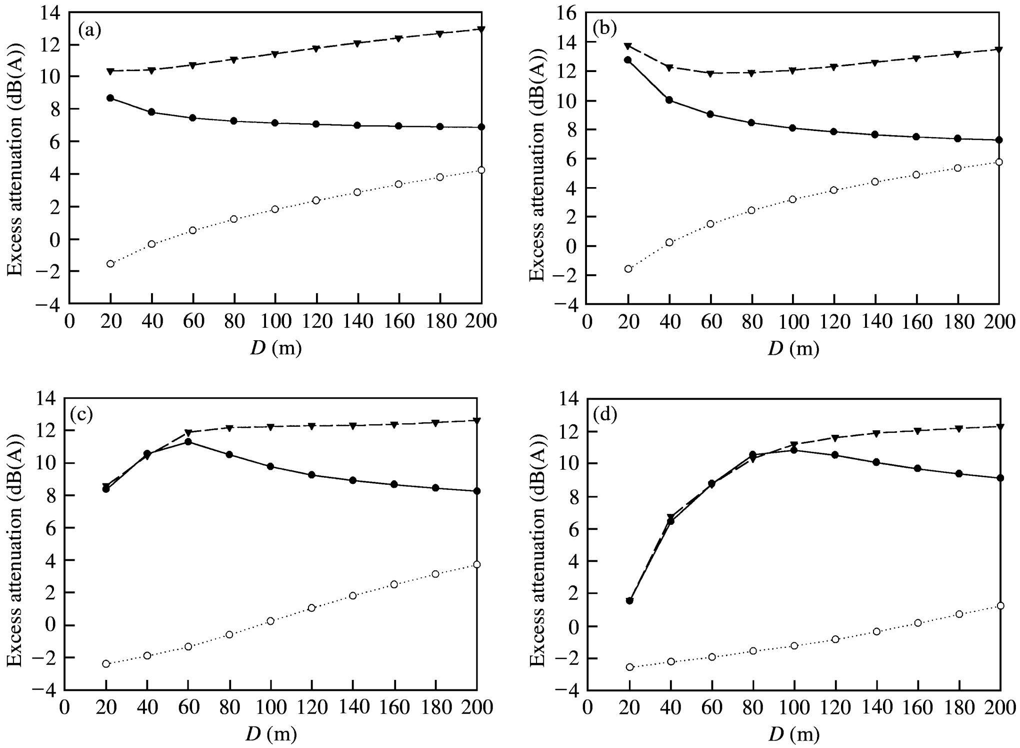

Figure 7. Excess attenuation for unshielded propagation over grassland, ·····○·····, and for a roadside barrier 3 m in height with grassland, —▼—, and rigid ground, —●— behind the barrier. Receiver heights are 0, 1·5, 4·5 and 7·5 m in (a), (b), (c) and (d) respectively. Coherent line source model.

values approximately 5 dB higher than those deduced from the individual effects. This suggests that it is necessary to consider the combined effect of the barrier and the grassland at all distances considered. In Figure 6(d), at a receiver height of 7·5 m the excess attenuation related to the barrier is greater at all distances than that of the grassland. The excess attenuation curve for the barrier on rigid ground and the barrier on grassland converge for low values of *D* as expected, since the diffracted rays are a large distance from the ground and the propagation distance is low. For the lower barrier heights, the crossover of the curves occurred at shorter distances, and for greater heights, at longer distances. For the situations considered, the excess attenuation for the combined effects generally exceeded the results for the individual effects, by values up to 10 dB.

Figure 7(a–d) shows similar results for the coherent line source model. In this case, the barrier attenuation predominates over the grassland attenuation for all conditions considered, except at a barrier height of 2 m, receiver height of 1·5 m. There were generally lower differences between the excess attenuation predicted from the individual curves and the curve for the combined effect, up to 4 dB. At shorter distances from the barrier for greater receiver heights, the barrier attenuation curve and the curve for the combined effects coincide.

3.3. MEDIAN BARRIERS

The median barrier is 1 m in height and positioned in the middle of the central reservation, as shown in Figure 3. Both sides have sound absorbent surfaces with

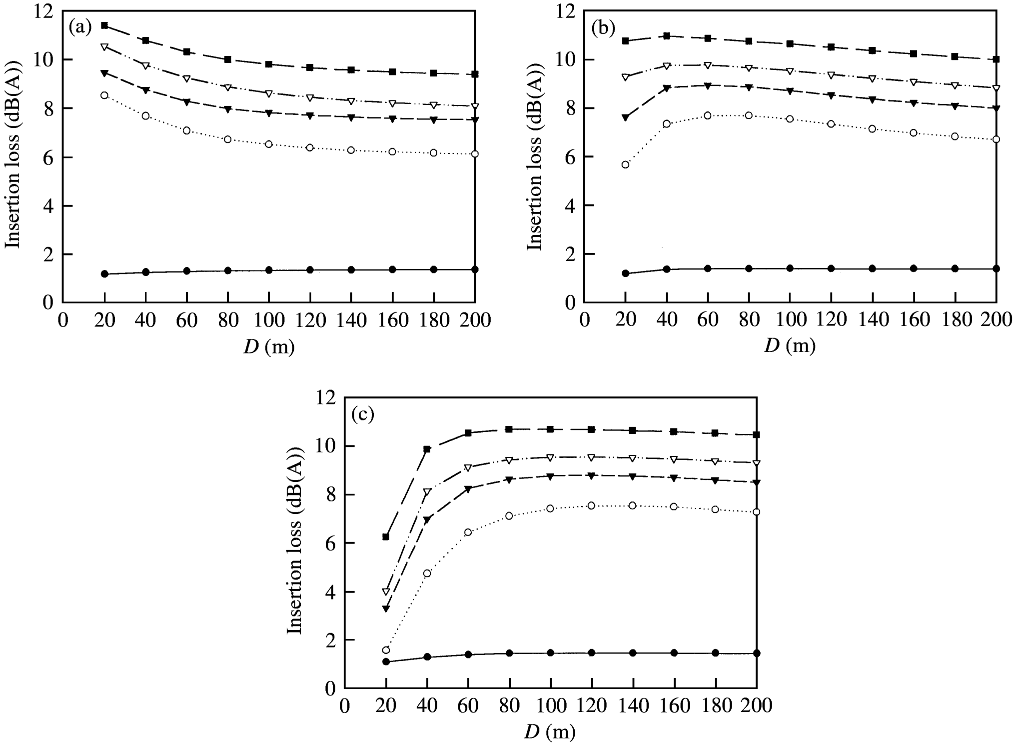

Figure 8. Insertion loss for various barrier configurations involving a median barrier. Rigid ground. —●—, 1 m median barrier; ·····○·····, 2 m roadside barrier; —▼—, 2 m roadside barrier and 1 m median barrier; —▽—, 3 m roadside barrier; —■—, 3 m roadside barrier and 1 m median barrier. Receiver heights in (a), (b) and (c) are 1·5, 4·5 and 7·5 m respectively.

characteristics as defined in Table 1. In this case, the height of each of the line sources was 0·1 m in order to model tyre noise accurately and the incoherent source model was used. Five barrier configurations were considered: (1) 1 m median barrier, (2) 2 m high roadside barrier, (3) 2 m high roadside barrier with median barrier, (4) 3 m high roadside barrier and (5) 3 m high roadside barrier with median barrier.

Figure 8(a–c) shows the insertion loss when the ground behind the barrier is rigid, for receiver heights of 1·5, 4·5 and 7·5 m respectively. The reduction in insertion loss close to the barrier when the receiver height is 4·5 and 7·5 m is a result of some of the source lines being visible from the receiver position. The insertion loss of the median barrier is between 1 and 1·5 dB for all positions. The difference in insertion loss between the 2 and 3 m roadside barriers alone is generally about 2 dB but is up to 4 dB for some receiver positions where visibility of the sources is involved. For combined roadside and median barriers, the insertion loss is between 1 and 1·5 dB greater than that for the corresponding roadside barrier alone. Increased values are observed where visibility effects occur. For receivers in the shadow region, the insertion loss of a median barrier with a 2 m roadside barrier is about 0·5 dB lower than the result for a 3 m roadside barrier alone.

Figure 9(a–c) shows the insertion loss when the ground behind the barrier is grassland, for receiver heights of 1·5, 4·5 and 7·5 m respectively. The trends are similar to those for the rigid ground cases except that there is reducing insertion loss with increasing distance. This is a result of the ground attenuation effect that occurs in the unshielded case from which the insertion loss is determined. The insertion loss of the median barrier is between 1 and 2 dB

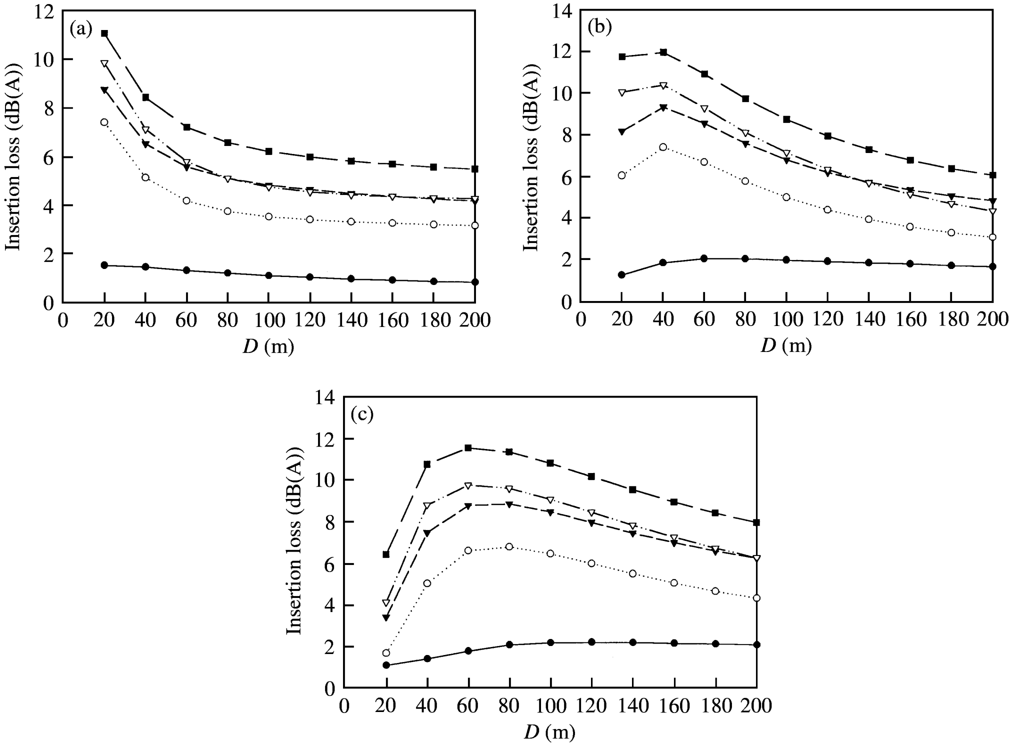

Figure 9. Insertion loss for various barrier configurations involving a median barrier. Grassland. —●—, 1 m median barrier; ·····○·····, 2 m roadside barrier; —▼—, 2 m roadside barrier and 1 m median barrier; —▽—, 3 m roadside barrier; —■—, 3 m roadside barrier and 1 m median barrier. Receiver heights in (a), (b) and (c) are 1·5, 4·5 and 7·5 m respectively.

for all receiver positions. The difference in insertion loss between the 2 and 3 m roadside barriers alone is similar to that for rigid ground. For combined roadside and median barriers, the insertion loss is between 1 and 2 dB greater than that for the corresponding roadside barrier alone. The insertion loss of a median barrier with a 2 m roadside barrier is similar to that for a 3 m roadside barrier alone for many receiver positions.

4. CONCLUSIONS

The ground attenuation has been calculated by using both the coherent and incoherent line source models and compared with standard values, which were derived primarily from site measurements [1]. For the lower receiver heights, the coherent model agreed more closely with the standard method [1], which predicts the L_{A10} levels. The coherent model results are known to predict well the propagation effects from point sources [4]. L_{A10} levels are related to the peaks of sound and weight more highly the sound contribution from vehicles close to the receiver so that a model simulating a localized source may be more appropriate in this case. An incoherent line source may be expected to predict attenuation effects in L_{Aeq} better since this is an overall energy average. However, it is unlikely that the ground and barrier attenuation effects in L_{Aeq} and L_{A10} levels will be markedly different.

Air attenuation can be included in the prediction of sound propagation from a point source. If a line source is approximated by a series of point sources, then air attenuation can be applied to each source. For the continuous line source model used here it is not possible to include this effect which is expected to be significant at higher frequencies and towards the extremities of the source line: i.e., for long propagation distances. In the incoherent line source case, there will be an overestimation of the contributions to the sound level at the receiver from the remote sections of the source. It is difficult to assess the effect in the coherent source case but it may be less important in this case since it appears that this model emphasizes the effects near the cross-section through the source and receiver.

The numerical models have been used to assess the efficiency of determining the attenuation of a barrier on grassland by using either the barrier attenuation or the grassland attenuation, whichever is greater. Both models indicate that in many cases, the combined effect is significantly greater than that deduced from the individual effects.

A sound-absorbing median noise barrier 1 m in height produced consistent values of insertion loss of between 1 and 2 dB over the range of receiver positions and ground conditions considered. When the median barrier was used in conjunction with a roadside barrier, it produced a consistent improvement in insertion loss of between 1 and 2 dB over the range of conditions considered. The consistency of the results is attributable to the broad averaging taking place over the propagation conditions for the six, incoherent, line sources. The results are broadly in agreement with the measurements of Watts [3].

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