Proceedings of the Institute of Acoustics

NUMERICAL MODELLING OF PARALLEL NOISE BARRIERS

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1. INTRODUCTION

Noise barriers are frequently used in the abatement of road traffic noise. In situations where protection is required on both sides of the road, parallel barriers may be used. However, it is well known that the insertion loss obtained behind a single barrier can be reduced by approximately 3dB following installation of its parallel counterpart on the opposite side of the road. This degradation in performance can be reduced by incorporating absorbing materials on the sides of the barriers facing traffic, or by sloping these faces by a small angle. Both methods appear efficient in simple model investigations, but the former is generally preferred in practical use. This is because the latter method involves only a redirection of the sound energy and unexpected effects are possible in actual site and atmospheric conditions.

It is desirable to be able to predict these effects and various methods have been developed to achieve this, which incorporate adaptations of wave theory and empirical results. The CROSECT model [1] calculates traffic noise levels from highways with complex cross-sections using ray path techniques for defining possible reflections. Several similar models are available in the USA [e.g. 2].

In this paper, a method of predicting the effects of parallel noise barriers using a boundary element numerical model is outlined. The results of the model are discussed and compared with other prediction methods. Shortcomings in the model are identified and a method of overcoming these is described and investigated. The boundary element model is two-dimensional. A method of converting the results to equivalent point source values is detailed and the changes between two- and three-dimensional results are discussed.

2. THE NUMERICAL MODEL

The model [3,4] is two dimensional and care is necessary in defining the three dimensional system to which it is equivalent. In three dimensions, the barrier is of infinite length with uniform cross-section and surface treatment along its length. The source becomes a coherent line source, parallel to the barrier and also of infinite length.

The method, which is a numerical approach, uses the boundary element method applied to a boundary integral equation which is similar to the Kirchhoff-Helmholtz equation. The integral equation is formulated using Green's theorem and the Green's function for propagation over a homogeneous impedance plane is used as the fundamental solution. This means that the integral only extends over the barrier cross-section, which is therefore the only part of the boundary to be divided into elements. These boundary elements are no greater than $\lambda/5$ in length (where λ is the wavelength of the source) and although smaller element lengths give increased accuracy, there is a corresponding increase in computation time, especially if the simulations use absorbing ground rather than rigid ground as the boundary condition.

Results are presented in terms of Insertion Loss (defined by $IL = SPL_g - SPL_b$, where SPL_g is the Sound Pressure Level at the receiver position with only the flat ground present and SPL_b is the level following the introduction of the barrier). The broad band insertion loss is calculated for each receiver position - this is the prediction for a source with a single vehicle, A-weighted, road traffic noise spectrum. These are calculated by finding the attenuation, with and then without the barrier present, of each ninth octave centre frequency between 58 & 3415 Hz using the boundary element model. These figures are then applied to a ninth octave A-weighted spectrum characteristic of a single road vehicle in free-field conditions to give SPL values with and without the barrier.

3. RESULTS USING LINE SOURCES

The simulations carried out here have been based around a barrier separation of 34.3m (for vertical parallel barriers), this distance being the width of a 6 lane motorway with a hard shoulder on each carriageway. Receiver positions have been set at 20, 40 and 80m from the outside face of one of the barriers and at heights of 1.5 and 4.5m (corresponding to ground floor and first floor window heights).

The situation being modelled (for all barrier arrangements) is the simplest - 2 source positions (each considered in a separate simulation), each at a height of 0.5m above the carriageway, each one at a distance of 7.8m from the inside face of one of the barriers, to represent a vehicle travelling in the inside lane of each carriageway [Figure 1]. Obviously, the accuracy of the results in relation to road conditions varies greatly depending on the number and placement of sources. A minimum of 2 source positions are necessary for modelling almost any road. This number will also increase if it is desired to model different types of traffic, since the height of the source above ground will vary depending on the vehicle. The sound pressure levels for each receiver position in each simulation are then logarithmically combined in the standard way to produce a single SPL value at each receiver showing the effect of both sources at the same time.

Predicted degradation in insertion loss due to the addition of the second barrier at a series of receiver positions using the boundary element model are shown in Table 1. These can be compared with results obtained from the CROSECT method and also using the standard UK traffic noise prediction method CRTN [5]. The CRTN method has been developed from measured data and its predicted insertion loss degradation values are significantly different to those of the boundary element method. In both the CRTN and CROSECT predictions, all traffic streams are combined to produce a single line source, located 3.5m from the edge of the nearside carriageway. As a result, all receiver positions (as considered here) lie within the shadow zone. However, in the case of the boundary element model, where 2 source positions are used, the highest receivers at 20 and 40m from the barrier lie in the illuminated zone generated by the source furthest away. It should also be noted that the CROSECT model is a ray model which does not consider directly the reflection of rays from the sides of vehicles. The results from the CROSECT model are systematically and significantly greater than those obtained using the CRTN method and the results from the boundary element model greater than those from CROSECT for the most part. Also the CRTN results lie within a range of approximately 1 dB, whilst the results from the other models are within a range of between 3-3.5 dB.

4. MODIFIED PROCEDURE

The boundary element model provides an accurate determination of the wave field for the particular problem posed. However, there are three significant differences between this and the practical situation:-

i) the model assumes that the ground is perfectly flat and that the barriers are exactly vertical,

ii) the model assumes that all propagation in the region between the barriers is unimpeded. In a roadway situation, this is clearly not true, since propagation will be impeded by the sides of vehicles,

iii) the model is two-dimensional so that the three dimensional situation which is modelled is of a coherent line source in an infinite roadway of constant cross-section. In practice, vehicles approximate to point sources so that rays suffering multiple reflections from the barriers attenuate at a rate of 6dB/doubling of distance whereas, in the model, the attenuation is 3dB/doubling of distance.

Various options are available to overcome these differences although some are more effective than others. A small change in the vertical angle of the barriers (Table 2) or a more accurate reproduction of their profile will have some effect, as will changing the profile of the ground surface. However, the latter is less preferable due to a considerable increase in the computational expense of the solution.

In order to simulate propagation impeded by the sides of vehicles, a "box-shield" has been incorporated into the revised model. Being two-dimensional, the shield is formed from 3 faces (Figure 2), each having an absorbent lining. The horizontal internal faces have the same treatment (a statistical absorption coefficient, α, of 0.4) and the face at the rear of the shield an α value of 0.9. The source is positioned midway between the horizontal faces and vertically aligned with the front of the shield. The placement of the source at this position is important and results in two effects - the first is to "halve" the angle of propagation, i.e. waves from the source radiating into the shield are effectively cut out (see Figure 2). To simulate sound propagation from the other side of the vehicle, it is necessary to undertake an additional simulation with the shield rotated through 180°. The second effect is to absorb reflections from the barrier with a low angle of incidence. The angle θ through which these reflections are affected will depend on the separation, y, of the horizontal faces of the shield and the distance, x, between the shield and barrier (Figure 2). The final results were generated using this approach for 2 source positions, which involved the addition of results from 4 simulations. In Table 1, the results using this approach are given for the standard barrier geometry. A reduction of the order of 3 dB in the insertion loss degradation in comparison with the basic boundary element model results is observed. In both cases, the source strength is identical. The changes are attributable to the absorption of the sound reflected from the barrier by the box shield.

Results given in Table 2 show the effect of incorporating the shield at the same time as tilting the barriers. It is possible to relate directly the data in Table 2 with that in Table 1. Incorporating both the tilting of the barriers and the box shield within the boundary element model will decrease the insertion loss degradation to bring the predicted values closer to those obtained using the CRTN method. We would expect the CRTN results to give a good indication of the practical situation since the method is derived from site measurements.

To investigate the third difference, it is interesting to modify the results produced by the model such that they are equivalent to those for a point source. In undertaking this conversion, it is necessary to make a number of assumptions:-

i) that the line from the point source to the receiver is perpendicular to the barriers,
ii) that each barrier has a definable highest point which is visible from the source position. The highest point of the front barrier should be visible from the receiver position and that of the rear barrier should be visible from the top of the front barrier.,
iii) that the barriers are infinitely long,
iv) The pressure component at a particular receiver for a specific ray path (in the line source case) is multiplied by $\frac{1}{\sqrt{R}}$ to convert to a point source, where R is the length of that ray path from source to receiver.
v) that there are only 2 significant contributory ray paths-
R_1 - the diffracted path from the source to the top of the front barrier to the receiver,
R_2 - the diffracted path from the source to the rear barrier to the top of the front barrier to the receiver.

and that these ray paths are assumed to be incoherent due to the large path difference and large frequency bandwidth.

The conversion is applied to the A-weighted results and the method is as follows:-

The total sound pressure level at the receiver due to both paths for a line source, *SPL*, is

$$SPL = 10\log_{10}(10^{(SPL1/10)} + 10^{(SPL2/10)}) \quad \text{.......... (1)}$$

where *SPL*1 is the pressure due to R_1 and *SPL*2 is the pressure due to R_2.
Rearranging and inverting gives

$$SPL2 - SPL1 = 10\log_{10}(10^{(SPL-SPL1)/10} - 1) \quad \text{.......... (2)}$$

Let us define the insertion loss degradation in the line source case, *DEGL*, as the difference between the insertion loss for the front barrier (SPL_D-$SPL1$) and the insertion loss for both barriers (SPL_D-SPL),

$$DEGL = SPL_D - SPL1 - (SPL_D - SPL)$$

$$= SPL - SPL1 \quad \text{.......... (3)}$$

where SPL_D is the direct sound pressure level
Therefore the difference between the SPLs of the two ray path contributions (for the line source), *DSPLL*, is (from equations (1) and (2))

$$DSPLL = SPL2 - SPL1$$

$$= 10\log_{10}(10^{DEGL/10} - 1) \quad \text{.......... (4)}$$

Now calculate the path lengths for the two ray paths, R_1 and R_2 (Figures 3a and 3b)-

R_1 - either direct from source to receiver (if the latter is visible from the source) or via the top of the front barrier.

R_2 - If the front barrier is not visible from the image, then either

i) from the image of the source in the rear barrier direct to receiver, if the image is visible, or

ii) from the image of the source to the top of the front barrier to the receiver

Otherwise either

iii) from the image of the source to the top of the rear barrier to the receiver, or

iv) from the image of the source to the receiver with diffraction at the top of each barrier

Now for a line source

$$Intensity \propto \frac{1}{R} \quad \& \quad pressure \propto \frac{1}{\sqrt{R}}$$

whilst for a point source,

$$Intensity \propto \frac{1}{R^2} \quad \& \quad pressure \propto \frac{1}{R}$$

Therefore, to convert a SPL from a line source to a point source,

$$SPL_{point} = SPL_{line} + 10\log_{10}\left(\frac{1}{R}\right) \qquad \text{.......... (5)}$$

So to convert $DSPLL$ to a point source equivalent, $DSPLP$

$$DSPLP = SPL2 + 10\log_{10}\left(\frac{1}{R_2}\right) - SPL1 - 10\log_{10}\left(\frac{1}{R_1}\right)$$

$$= SPL2 - SPL1 - 10\log_{10}\left(\frac{R_2}{R_1}\right) \qquad \text{.......... (6)}$$

Therefore, from equation (2)

$$DSPLP = 10\log_{10}(10^{DEGP/10} - 1)$$

where $DEGP$ is the insertion loss degradation for the point source case. Rearranging this equation gives

$$DEGP = 10\log_{10}(1 + 10^{DSPLP/10}) \qquad \text{.......... (7)}$$

This degradation loss is therefore calculated for each receiver position in turn. Although these results are of use individually, they can be combined to produce a single value for the insertion loss degradation due to multiple point sources. The procedure is as follows:

Let $SPLL_j$, j=1,2... denote the sound pressure level calculated by the standard 2-dimensional boundary element model and $SPLP_j$, j=1,2... the point source equivalent, when the source is at position j and only the front barrier is present. Assuming that the main ray path is R_j (as defined previously), then from equation (5),

$$SPLP_j = SPLL_j - 10\log_{10}(R_1) \quad \text{.......} \quad (8)$$

We have already calculated the insertion loss degradation for a point source $DEGP_j$, j=1,2... with the source at point j, when the rear barrier is inserted. Therefore, the sound pressure level at the receiver point with both the front and rear barrier present is

$$SPL'_j = SPLP_j + DEGP_j \quad \text{.......} \quad (9)$$

Therefore, the insertion loss degradation with all the point sources present, ILDP, is

$$ILDP = SPL' - SPLP \quad \text{.......} \quad (10)$$

where $SPLP$ is the logarithmic sum of $SPLP_1$, $SPLP_2$ ... and SPL' that of SPL'_1, SPL'_2 ....

5. RESULTS USING POINT SOURCES

Table 3 compares results for the degradation in insertion loss from the boundary element model with identical results adjusted for a point source situation, for two parallel barrier arrangements (in both cases neither barrier tilting nor shield have been incorporated). In the second case, the barrier furthest from the receiver positions has been made absorptive (the inner face of the barrier having an α value of 0.7) - this will have the effect of bringing the performance of the arrangement closer to that of just a single barrier.

The attenuation rates for the point and line source cases are 6 and 3 dB/doubling of distance respectively. For a single barrier the insertion loss is very similar for the point and line source cases, since the path lengths of the direct ray and the ray over the barrier are approximately equal. However for the parallel barrier condition, the ray reflected from the opposite barrier is much greater in length than the ray over the near barrier and this difference causes the appreciable change between the line and point source results in Table 3. When the far barrier is absorbent, the effect of the ray reflected from this surface is reduced and this effect is illustrated in Table 3.

6. CONCLUSIONS

Several problems have been identified in the simulation of noise propagation from parallel noise barriers using boundary element models and point sources. Results close to those predicted by the CRTN method have been obtained by introducing modifications which simply model the presence of a vehicle body and the effects of imperfections within the barrier geometry. We have shown that this numerical approach is an effective method for analysing parallel noise barriers provided that such factors are taken into consideration.

A straightforward approximation has been developed for the transformation of line source results to those of a point source. The adjustment procedure used for calculating the point source values in Table 3 does not produce results which detail the absolute performance of the barrier. However combining data from both the boundary element model and stages of this adjustment will allow the *insertion loss* resulting from the use of the arrangement with multiple point sources to be calculated.

Whilst not necessarily producing exact results, the model can be used as a basis for generating predictions as to the relative performance of parallel barrier arrangements in terms of both point and line source cases.

7. REFERENCES

[1] TOBUTT D.C. and NELSON P.M., A model to calculate traffic noise levels from complex highway cross-sections. Transport & Road Research Laboratory, Research Report 245, Department of Transport, 1990

[2] SLUTSKY S. and BERTONI H.L., Analysis and programs for assessment of absorptive and tilted barriers. Transportation Research Record 1176, Transportation Research Board, National Research Council, Washington DC, pp.13-22, 1987

[3] CHANDLER-WILDE S.N. and HOTHERSALL D.C., The boundary integral equation method in outdoor sound propagation. Proceedings of The Institute of Acoustics, Vol.9, pp.37-44, 1987

[4] CHANDLER-WILDE S.N., HOTHERSALL D.C., CROMBIE D.H. and PEPLOW A.T., Efficiency of an acoustic screen in the presence of an absorbing boundary. Rencontres Scientifiques du Cinquantenaire: Ondes Acoustiques et Vibratoires, Interaction Fluide-Structures Vibrantes, Publication du Laboratoire de Mécanique et d'Acoustique (CNRS Laboratoires, Marseille), No.126, pp.73-90, 1991

[5] DEPARTMENT OF THE ENVIRONMENT, The calculation of road traffic noise. London, Her Majesty's Stationary Office, 1988

Receiver Positions		Degradation In Insertion Loss (dBA)			
Distance (m)	Height (m)	Boundary Element Model	CROSECT Model	CRTN Method	Boundary Element Model (Using Shield)
20.0	1.5	6.72	3.93	1.72	3.61
40.0	1.5	6.68	5.02	1.81	3.7
80.0	1.5	5.77	5.95	1.95	4.07
20.0	4.5	7.22	3.69	2.32	5.26
40.0	4.5	9.33	6.48	2.49	6.02
80.0	4.5	8.23	7.03	2.77	5.56

Table 1: Comparison of degradation in insertion loss obtained using different methods of calculation

Receiver Positions		Insertion Losses (dBA)				
Distance (m)	Height (m)	-2° Tilt[1]	+2° Tilt	0° & Shield	-2° & Shield	+2° & Shield
20.0	1.5	4.14	3.14	2.37	3.75	3.7
40.0	1.5	3.42	3.62	1.9	2.38	2.94
80.0	1.5	2.07	2.09	0.91	1.54	1.95
20.0	4.5	1.88	0.98	1.57	2.64	2.11
40.0	4.5	4.26	3.25	2.97	4.76	4.46
80.0	4.5	4.34	3.03	1.89	4.12	3.67

[1] Note that a negative tilt moves the top of each barrier towards the source.

Table 2: Comparison of insertion losses (from boundary element model) for modified parallel barrier arrangements relative to a vertical parallel arrangement with no box shield

Receiver Positions		**Degradation In Insertion Loss (dBA)**			
		Both Barriers Reflective		**Far Barrier Absorbent[1]**	
Distance (m)	**Height (m)**	**Line Source**	**Point Source**	**Line Source**	**Point Source**
20.0	1.5	6.72	4.57	1.42	0.80
40.0	1.5	6.68	5.26	1.15	0.79
80.0	1.5	5.77	4.96	1.41	1.12
20.0	4.5	7.22	5.37	1.52	0.96
40.0	4.5	9.33	7.82	1.94	1.43
80.0	4.5	8.23	7.18	1.83	1.46

1 Far Barrier refers to that barrier furthest from the receiver positions

Table 3: Comparison of degradations in insertion loss obtained from the boundary element model, with those adjusted to a point source scenario

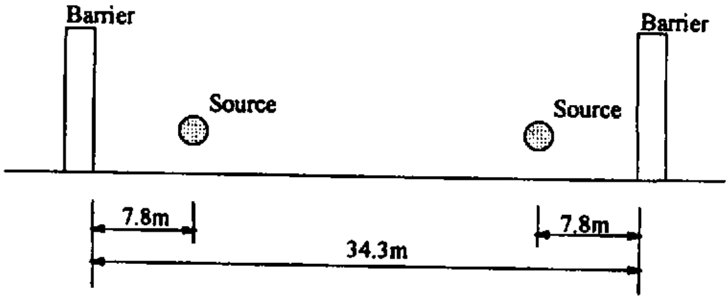

Figure 1: Layout of typical parallel barrier arrangement

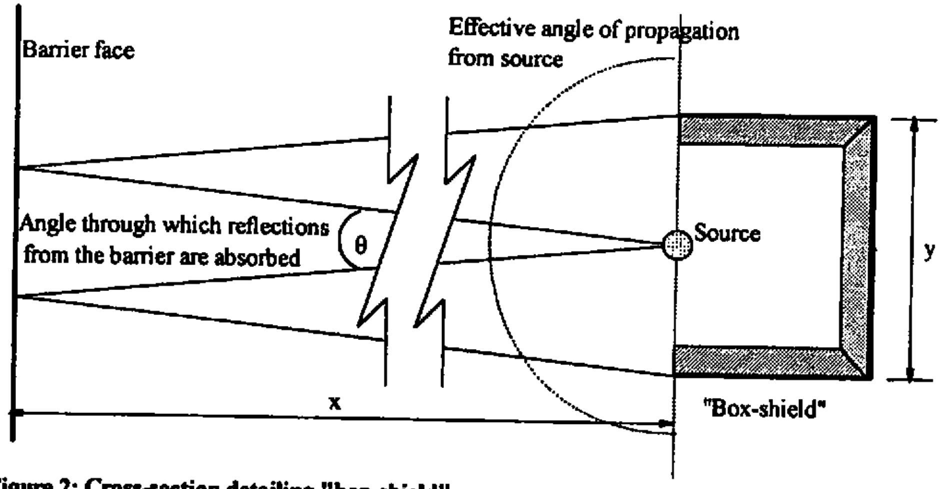

Figure 2: Cross-section detailing "box-shield"

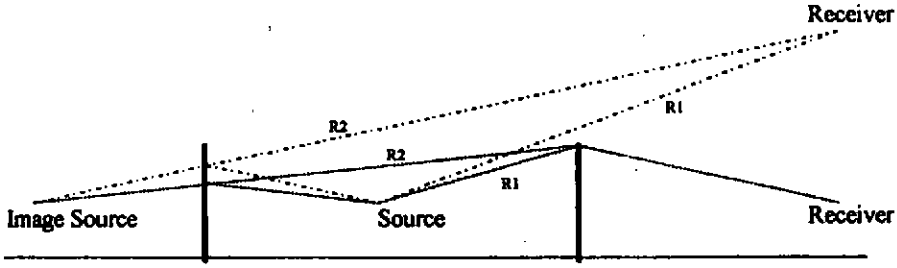

Figure 3a: Possible ray paths, including those where front barrier is not visible from image source

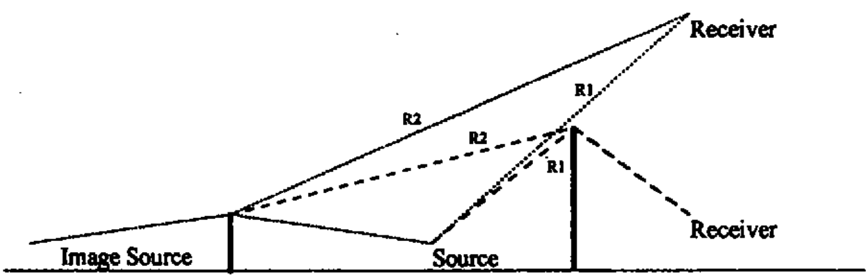

Figure 3b: Possible ray paths, including those where front barrier is visible from image source