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THE PRELIMINARY ESTIMATION OF THE NOISE FROM CONSTRUCTION SITES

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1. INTRODUCTION

Sophisticated deterministic models can be used to give accurate predictions of noise levels from construction sites. In such modelling the acoustic propagation parameters to be considered include source characteristics, topography, screening, nature of the ground, meteorological conditions such as wind speed and direction, and atmospheric absorption. By making simplifying hypotheses fast algorithms have been developed allowing computer ray tracing models to be implemented [1].
Reasonably accurate predictions can be obtained using less complex calculation methods. The method of calculation presented in the British Standard BS5228 [2] includes simplified adjustments for the nature of the ground, distance, reflections and screening, while considering both stationary and mobile activities. Nevertheless for extensive prediction work the final procedure warrants a software implementation and these increasingly are becoming available [3].
These deterministic methods however are not suitable for use in the earliest stages of a project. Carpenter [4] presented a closer examination of these issues, showing how at the planning stage of new developments the level of detail required for deterministic predictions is not available. For an assessment of site noise to become routine in the preliminary project-planning phase, alternative methods of prediction are required. These prediction methods would require comparatively granular data and produce predictions of noise levels with quantifiable standard deviations. Lewis and Gibbs [5] presented one such new approach, where through the application of stochastic modelling the noise sources and propagation processes can be represented statistically.
This paper reports an extension of the earlier work leading to a simple method for the prediction of open site industrial noise. The new approach complements deterministic prediction methods such as BS5228 but differs in that the noise generation and propagation processes are represented statistically. The system is derived from stochastic modelling and is distinctive in that it provides an estimate of the accuracy of the prediction, yet is simple and undemanding to put into practice. Nevertheless, propagation from extended sources is considered together with the effects of aspect ratio and site dimensions. The technique in intended be used as a strategic planning tool by allowing preliminary estimation of noise immissions to facilitate discussion in the earliest stages of a development. The prediction procedure is presented in an accessible form for use at the project planning stage by parties involved in potential noise complaints. Since quick prediction using granular input data allows a variety of site operation options to be easily considered, the new method means that planners, developers and environmental health officers will be able to respond with increased effectiveness, efficiency and flexibility.

2. BASIS OF PROPOSED METHOD

The basis of the proposed simplified estimation method is the replacement of a distribution of discrete sources by a point source of the same equivalent total sound power. This principle has recently been applied to complex sources such as construction sites [6]. However this work extends the principle to the quantification of the uncertainty in the predicted immissions by the application of stochastic modelling.

3. DESCRIPTION OF STOCHASTIC MODELLING METHOD

Simulation was performed using the Extend stochastic modelling software [7]. The dimensions of a simulated rectangular site were defined by X and Y, and sites included all 25 configurations of dimensions 50, 100, 150, 200 and 250m. Up to four stochastic sources were considered to be positioned at random locations within the boundary. The sound power of each stochastic source was allowed to vary randomly from full power, to tick-over, to off with a probability density function of 0.6: 0.2: 0.2 respectively. The equivalent sound power level of a stochastic source is therefore given by:

$$L_{Weq} = 10\log_{10}\left(0.6\times10^{L_{W_1}/10} + 0.2\times10^{L_{W_2}/10} + 0.2\times10^{L_{W_3}/10}\right) dBA \qquad (1)$$

where L_{w_1} is the full power level, L_{w_2} is the tick-over sound power level, and L_{w_3} is the off sound power level. Tick-over was taken as full power minus 10dBA, off as 0dBA, and 12 combinations of stochastic source powers were considered. The total equivalent sound power level of a site L_{Weq} is then given by:

$$L_{Weq} = 10\log_{10}\left(10^{L_{W_{eq1}}/10} + 10^{L_{W_{eq2}}/10} + 10^{L_{W_{eq3}}/10} + 10^{L_{W_{eq4}}/10}\right) dBA \qquad (2)$$

where $L_{w_{eqr}}$ is the equivalent sound power level of respective sources.

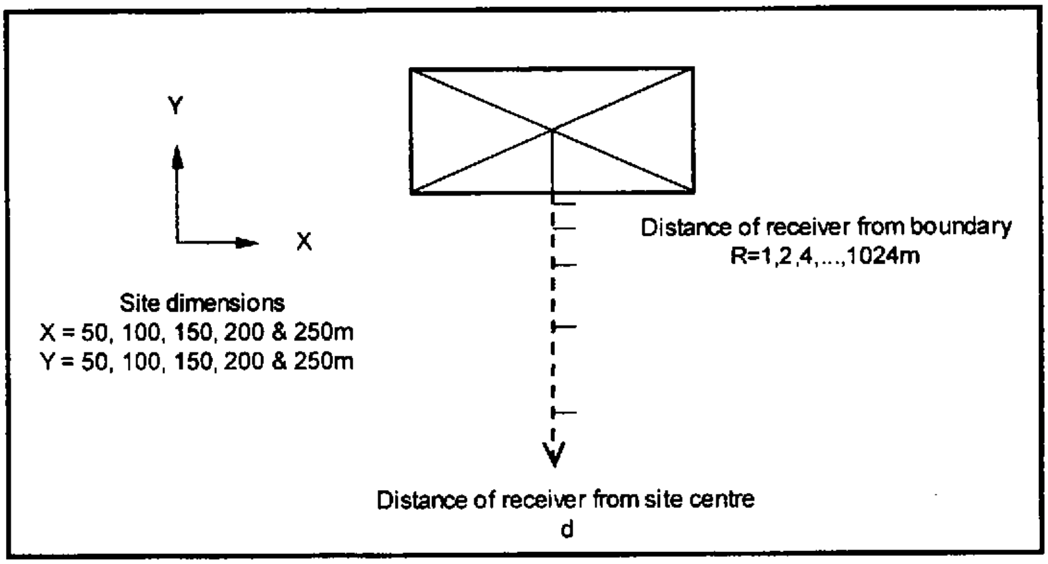

Figure 1: Schematic of construction site and receiver positions used in stochastic modelling

A schematic of the construction site and receiver positions is shown in figure 1. For each random position and sound power variation the sound pressure level at a series of receivers a distance R along a normal to the site X boundary through the site centre was calculated assuming hemispherical propagation over a hard plane. Receivers were considered at distances 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, and 1024m from the boundary. The mean and standard deviation in sound pressure level was determined at each of the 11 receivers, for each of the 25 sites, for each of the 12 stochastic source combinations.

4. RESULTS OF STOCHASTIC MODELLING

An example of the stochastic predictions for a site of dimensions 50x50m is shown in figure 2.

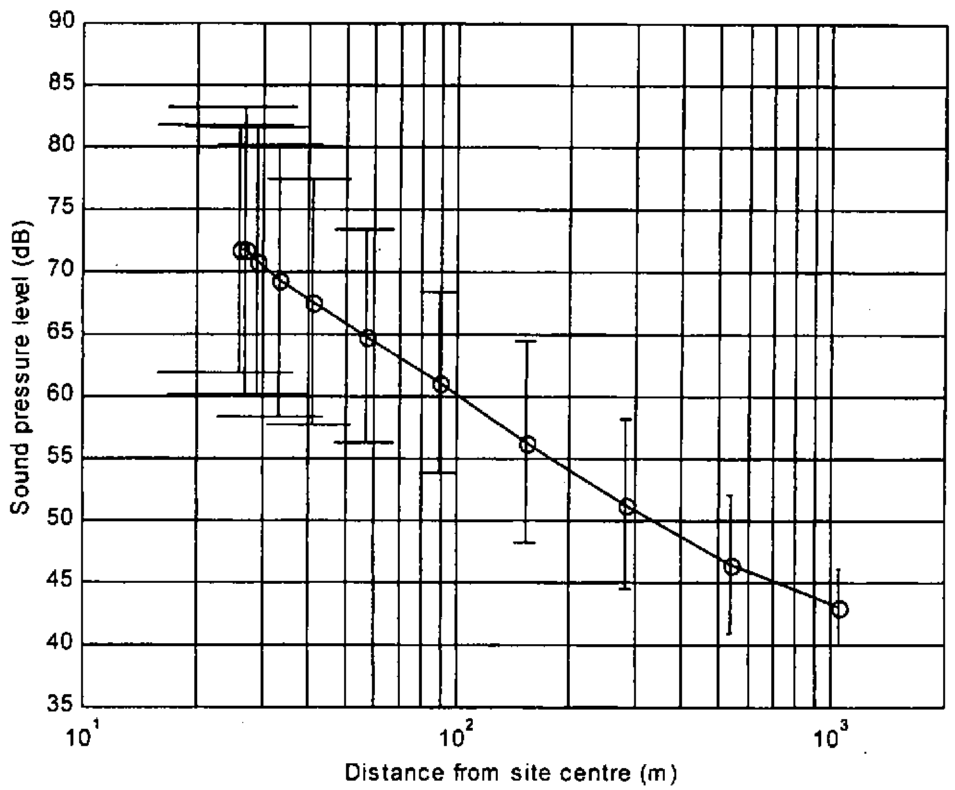

Figure 2: Stochastic predictions of sound pressure levels at receiver distances R from the centre of the simulated construction site boundary. Predictions of mean sound pressure level at receiver shown by (O), error bars shows predictions of ± 2 standards deviations..

The maximum sound power levels of each of the four stochastic sources were 110, 100, 100 & 100dBA and a background noise level of 40dBA was assumed. Predictions of mean sound pressure level at each receiver are shown together with shows predictions of ± 2 standards deviations. Assuming normal distribution of sound pressure levels this includes 95% of cases. It is seen that the standard deviation in sound pressure level is greatest closest to the site boundary, while the variation about the mean is seen to decrease as the receiver distance increases and the distributed source approximates more closely to a point source.

5. PROPAGATION FROM EXTENDED SOURCES

The basis of the estimation method is that the distributed source can be modelled in terms of radiation from a point source with the fall off in sound pressure level initially assumed to be 6dBA per doubling of distance. This assumption will obviously fail for aspect ratios (X/Y) which are not close to 1. For example, as the aspect ratio increases and become very large the site will resemble a line source and thus the fall off in sound pressure level will tend to approach 3dB per doubling of distance. Therefore, the stochastic data was analysed to investigate the variation of fall off with doubling of receiver distance as a function of site aspect ratio X/Y in order to establish an empirical correction. The fall off of mean sound pressure level with doubling of receiver distance was found to vary with the number of sources in the stochastic simulation with the 4 source combinations closest approximating to a point source for a site aspect ratio of 1. Figure 3 shows the fall off with doubling of distance for all the stochastic combinations of sources and sites together with the following expression over an aspect ratio range of 0.1 to 10:

$$f = -1.5\log_{10}\left(\frac{X}{Y}\right) + 6 \tag{3}$$

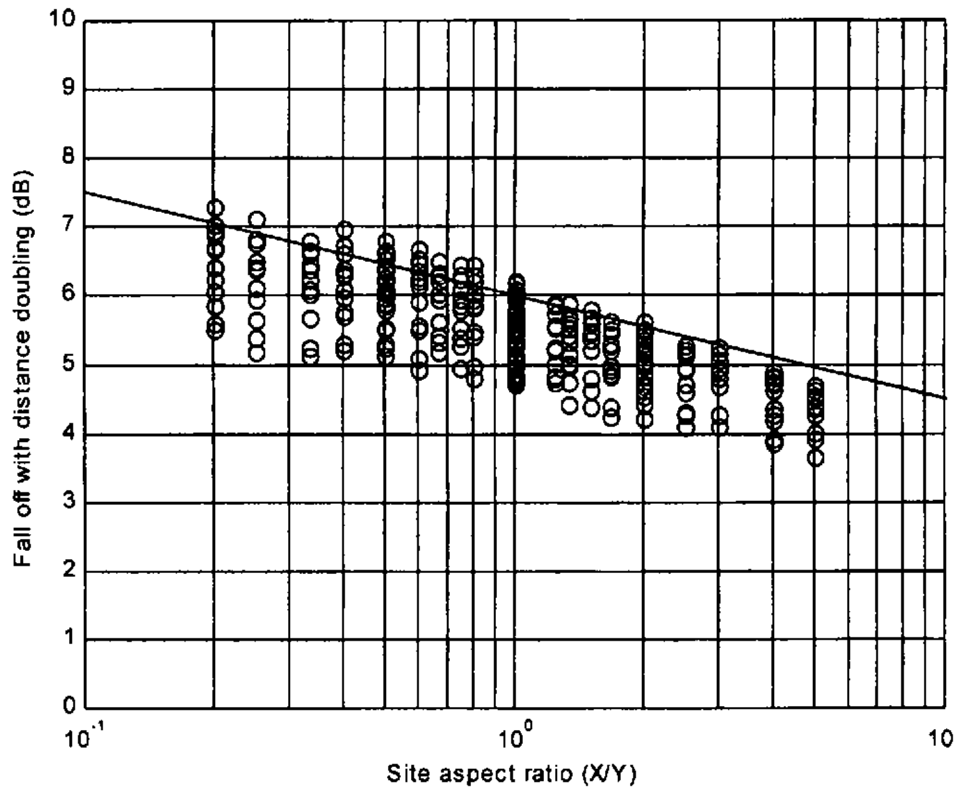

Figure 3: Variation of fall off with distance doubling as a function of site aspect ratio for all stochastic sources and sites, showing approximated expression f = – 1.5 log (X/Y) + 6.

The stochastic data was further analysed to derive a relationship between the site aspect ratio, the equivalent sound power level of the site and the mean sound pressure level at a receiver. By analogy with propagation from a point or a line source an expression of the form $L_1 = L_W + m\log_{10}\left(\frac{X}{Y}\right) + c$ was hypothesised where L_1 is the mean sound pressure level at 1m from the site centre, L_W is the equivalent sound power level of the site, and m and c are constants. As with the investigation of fall off with distance doubling the derived expression was found to vary with the number of stochastic sources with the single source combination showing the greatest difference from the mean. Figure 4 shows the extrapolations to a point 1m from the centre of the site of the mean sound pressure level L_1 minus the equivalent sound power of site L_W for 2, 3 & 4 sources, together with the following expression:

$$L_1 - L_W = -15\log_{10}\left(\frac{X}{Y}\right) - 8 \tag{4}$$

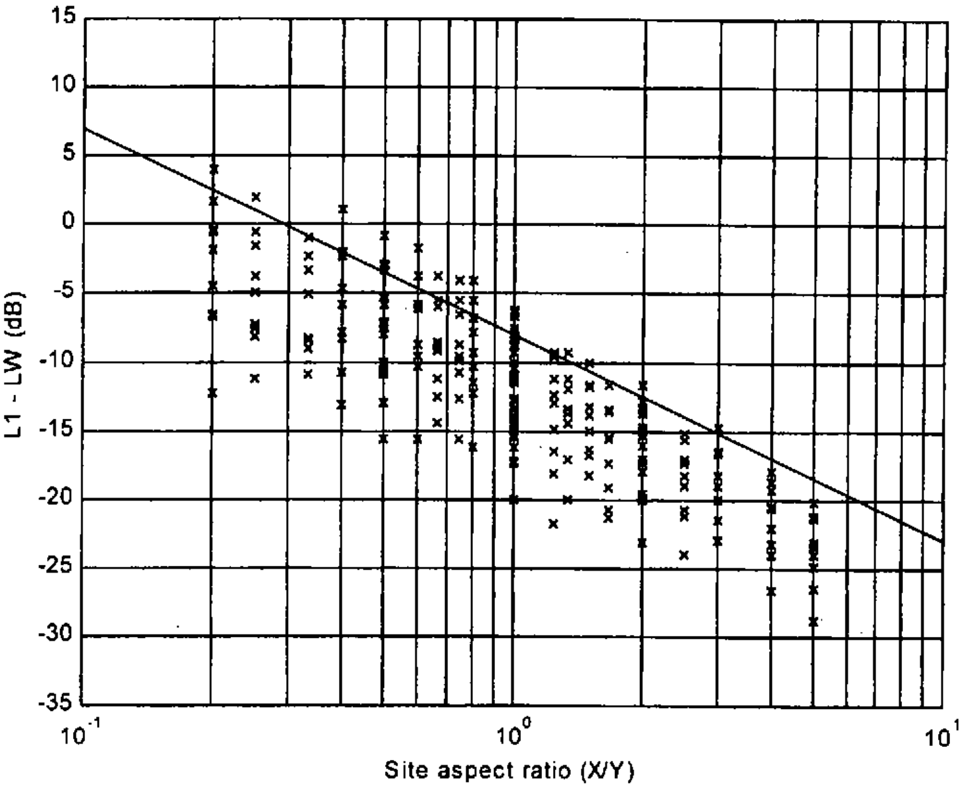

Figure 4: Extrapolations to 1m from site centre of mean sound pressure level L_1 minus equivalent sound power of site L_W for 2, 3 & 4 sources as a function of site aspect ratio (X/Y), showing approximated expression $L_1 - L_W = -15log_{10}(X/Y) - 8$.

These two expressions can be combined to give the following expression for the estimation of mean sound pressure level $L_p(r)$ at a receiver distance r from the centre of a site of total equivalent sound power level L_W and dimensions X and Y an aspect ratio range of 0.1 to 10:

$$L_p(r) = L_W - 20\log_{10}(r) - 15\log_{10}\left(\frac{X}{Y}\right) + 5\log_{10}(r)\log_{10}\left(\frac{X}{Y}\right) - 8 \tag{5}$$

Figure 5 shows a set of curves for the estimation of mean sound pressure level $L_p(r)$ at distance r from a construction site for various aspect ratios (X/Y) based on the above expressions. The curves are normalised to assume a standard equivalent site sound power L_W of 1mW ≡ 90dBA.

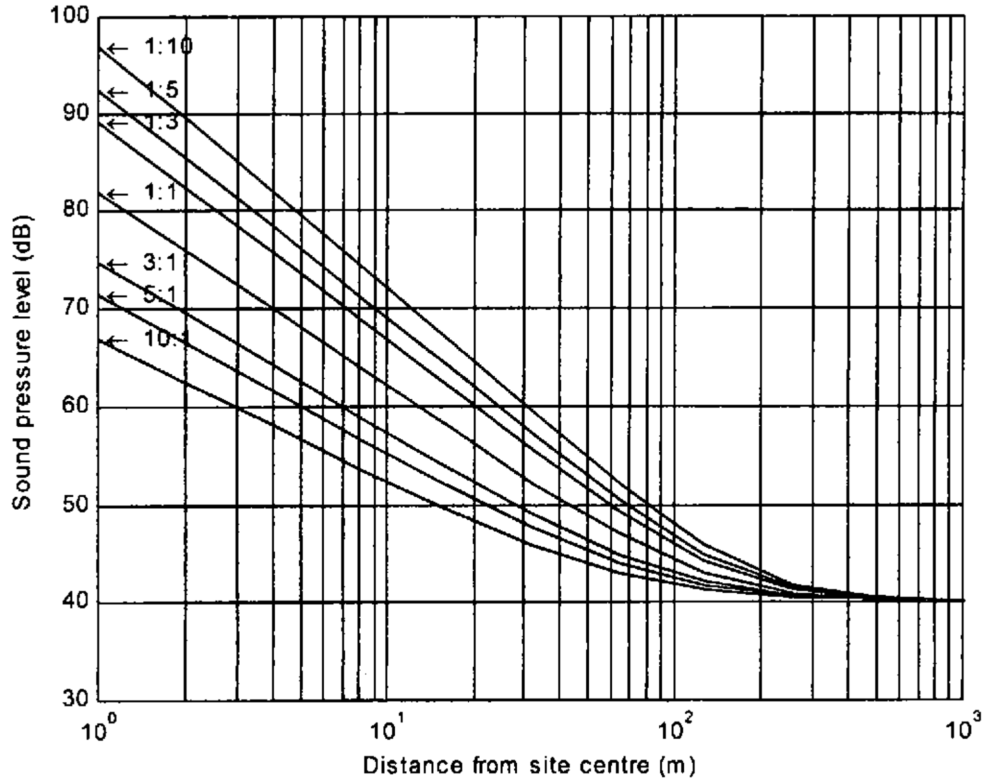

Figure 5: Normalised curves for the estimation of mean sound pressure level from a construction site of various aspect ratios (X/Y). Background noise level taken as 40dBA. Equivalent sound power of combined stochastic sources 1mW ≡ 90dBA.

6. ESTIMATION OF THE STANDARD DEVIATION.

The proposed simplified method for the estimation of the accuracy of the prediction of mean sound pressure level is based upon the properties of the standard deviation for normal distributions. For normal and moderately skewed distributions the maximum and minimum sound pressure levels at a receiver will occur at approximately ±4 standard deviations from the mean respectively [8]. For the stochastic model the maximum sound pressure level $L_{p\max}(r)$ at a receiver will occur when all the sources are operating at full power at the closest point to the receiver on the boundary. Conversely the minimum sound pressure level $L_{p\min}(r)$ at a receiver will occur when all the stochastic sources are off and only background noise is present. The standard deviation s is therefore estimated by the expression:

$$s(r) = \frac{L_{p\max}(r) - L_{p\min}(r)}{8} \quad (6)$$

where $L_{p\max}(r)$ is calculated using equation (5) assuming the maximum source powers acting from the closest point on the boundary to the receiver, and $L_{p\min}(r)$ is the background noise level.

7. COMPARISON OF STOCHASTIC PREDICTIONS AND SIMPLE ESTIMATIONS

Stochastic predictions and simple estimates of mean sound pressure level and standard deviations are compared in figures 6 and 7. The simple estimates are seen to perform best for many sources of similar mean sound powers. In figure 6 for example the maximum sound power levels of stochastic sources are 100, 100, 100, and 100 dBA and the site dimensions are 50x50m. The mean of the absolute value of the difference between stochastic prediction and simple estimate of mean sound pressure level at each receiver position is -0.2dBA, the negative value here indicating that the simple estimates tend to be higher than the stochastic predictions. The estimates of mean sound pressure level agree with the stochastic predictions within -0.7dBA at all receiver distances. The maximum difference in the standard deviations on the other hand is -2.3dBA while the mean difference is -0.7dBA. The simple estimation method is seen to tend to predict slightly larger standard deviations than the stochastic model.

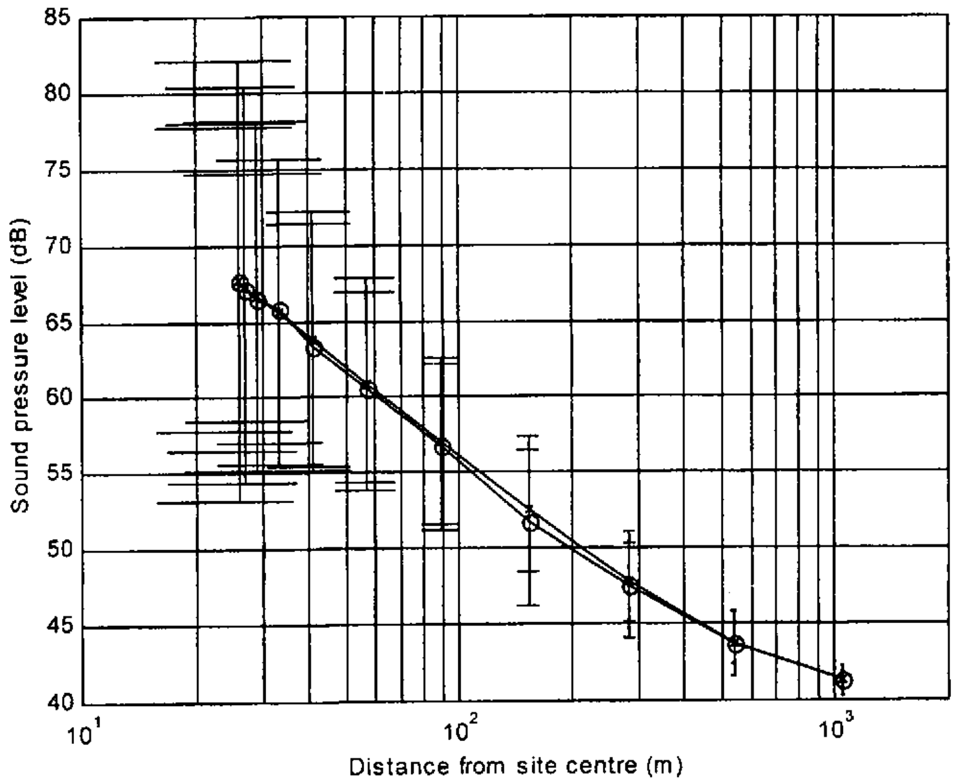

Figure 6: Comparing stochastic predictions (solid O) and simple estimates (dashed X) of sound pressure level and two standard deviations. Site dimensions are 50x50m, maximum sound power levels of stochastic sources are 100, 100, 100, and 100 dBA.

From an examination of a large number of configurations it was observed that the simple estimation method performs better for site aspect ratios (X/Y) closer to 1. For the source combination of figure 6 the mean of the absolute difference in sound pressure level is less than 1dBA and the maximum difference 1.8dBA. For sites of all dimensions for this source combination the mean of the absolute difference in standard deviations is less than 1dBA and the maximum difference 3dBA. This example shows the application of the simple estimation method under favourable conditions.

The practical useful limit of the method is illustrated by figure 7 comparing stochastic predictions and simple estimates for a site of dimensions 50x250m and maximum sound power levels of two stochastic sources of 110 and 100 dBA. Again the simple estimation is seen to predict higher mean sound pressure levels than the stochastic model. This example shows the application of the simple estimation method under least favourable conditions

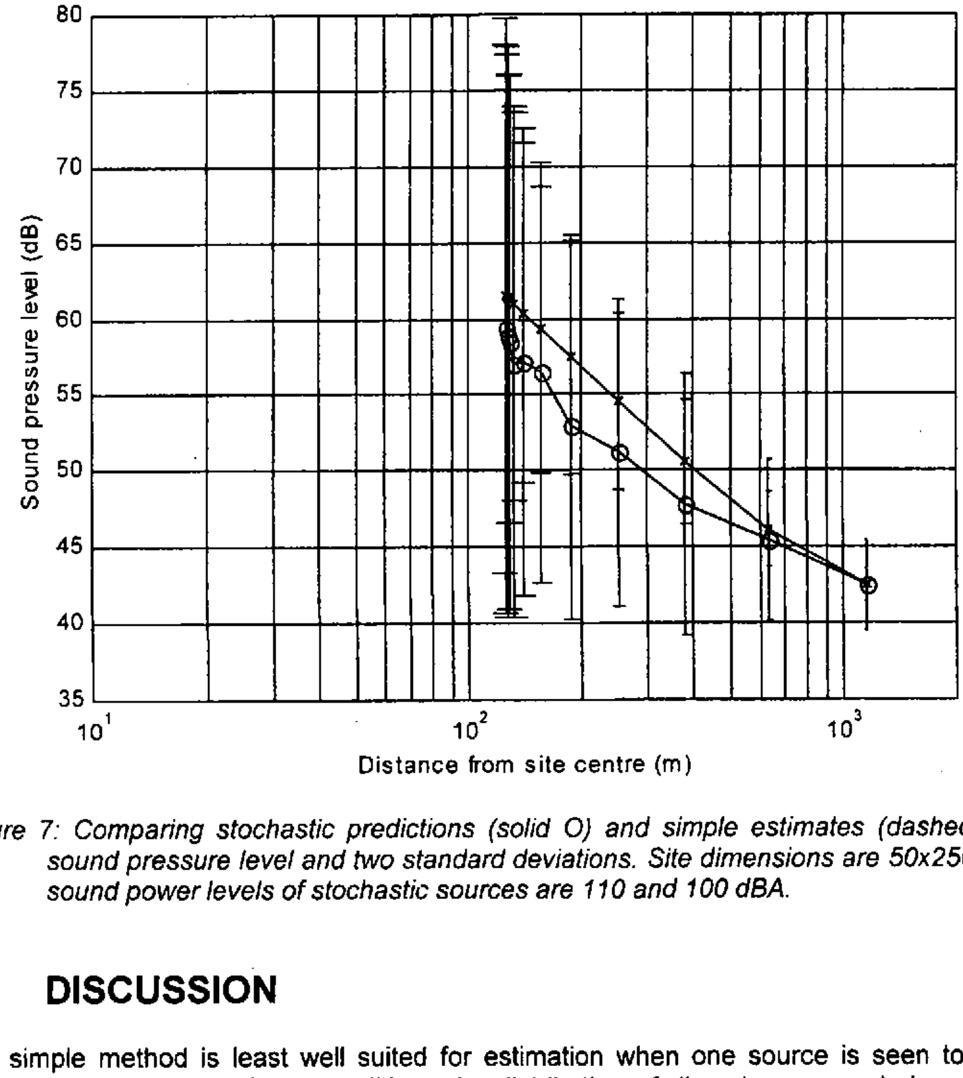

Figure 7: Comparing stochastic predictions (solid O) and simple estimates (dashed X) of mean sound pressure level and two standard deviations. Site dimensions are 50x250m, maximum sound power levels of stochastic sources are 110 and 100 dBA.

8. DISCUSSION

The simple method is least well suited for estimation when one source is seen to dominate by 10dBA or more. Under these conditions the distribution of discrete sources behaves least like a point source and the original hypothesis breaks down. The development of the estimation method included the extrapolation of the sound pressure level to a distance of 1m from the hypothetical equivalent point source at the centre of the site. It should not be supposed however that the technique is therefore valid for receiver distances within the site boundary. The standard deviation estimation method uses an assumption that the immissions take the form of a normal distribution. The work of Wentang [9] indicated that while this may be the case for processes such as excavation it is less likely to be the case for operations such as piling. Under these circumstances the method cannot be expected to provide accurate estimations of standard deviation.
It is intended that the simple estimation method be used as a strategic planning tool by allowing for preliminary estimation of noise immissions to facilitate discussion in the earliest stages of a

development. Consequently the prediction procedure is presented in a readily understood form so as to be straightforward to implement. Although this precondition means that approximations were made in the expressions derived from analysis of the stochastic data, consideration was given so as to develop the accessible algorithm without significantly compromising the accuracy of the estimation technique.
The estimation procedure is clearly dependant upon the quality of the source information defining the sound power of the on-site processes and periods of operation of the plant. While comparison against stochastic modelling is seen to be useful for the development of the simple estimation method validation should be performed against measurements made under a variety of conditions. However developments to the simple estimation method to be considered to increase its significance as a strategic planning tool include screening by barriers, soft ground attenuation and meteorological conditions.

9. CONCLUSIONS

A method has been developed based upon stochastic modelling for the estimation of the mean sound pressure level at a receiver a distance from a construction site. The technique provides an assessment of the accuracy of the prediction, yet is simple and undemanding to put into practice. The simple method is suitable for application with two or more stochastic sources of similar mean sound powers. If the dominant source is 10dBA or less above the combined sound power of the other sources the maximum error in estimation is 4.7dBA when compared with stochastic simulations for site aspect ratios between 0.2 and 5. Under similar conditions the maximum error in estimation of the standard deviation in sound pressure level at a receiver is 4.2dBA. The method provides more accurate estimations for three or more sources of approximately the same equivalent sound powers.

10. REFERENCES

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