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Technical Note

Proposal for revising the multiple screen approach in the General Prediction Method for industrial noise

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Contents

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1. Background and objective

It has for some years been known among the users of the General Prediction Method (GPM) when calculating noise from industrial plants in the noise prediction software SoundPLAN that unexpected calculation results are seen in some cases with more than one screen. For example, adding a third screen to a propagation case with two screens has been shown occasionally not to reduce the noise level as expected but to increase it.

The objective of this project is to analyze the calculation method for multiple screen prediction to understand the reason for this inexpediency and if possible, to propose a revision of the method that solves the problem.

2. Analysis of the calculation method for two or more screens

GPM was originally described in Report no. 32 (in English) from the Danish Acoustical Laboratory [1] and was later included the Danish guidelines (in Danish) from the Environmental Protection Agency (EPA) with a few minor simplifications [2]. The multiple screen approach of GPM is described in Appendix C of [1] and in Appendix 3 of [2]. It has been informed that the most commonly used software in Denmark, SoundPLAN, has based their version of GPM on the description in [1]. But it is generally not expected that differences between [1] and [2] can explain the inexpedient behavior, or at least only partly.

In [2], the first step in the multiple screen approach is to find all screens that may be included in the calculation by calculating the vertical path length difference δ_v from source to receiver over the screen. All screens with $\delta_v \geq 0$ are possible to be included in multiple screen calculation as the two most effective screens. If there is only one possible screen or if $\delta_v < 0$ for all screens, the screen effect will be calculated using the single screen approach including the screen with the largest value of δ_v. If two or more screens are found to be possible screens, the single screen effect ΔL_S is calculated for each of them, and the two screens with the smallest value of ΔL_S is chosen. ΔL_S include the reduction in screen effect due to a finite horizontal length of the screen and is therefore more accurate to use than δ_v. In [1], another approach is used based on the effective screen height corrected for finite horizontal screen length. It is stated in [2] that the difference between [1] and [2] is of minor importance which is likely to be the case. In the descriptions of [1] and [2], it is stated that it is sufficient in the one-screen case to choose the screen solely based on δ_v. However, this way the most effective screen is not necessarily found since the horizonal length of the screen is not considered. Like in the case with two or more screens the choice should have been based on ΔL_S.

The procedures in [1] and [2] with the mentioned modification appear appropriate for selecting the most effective screen but less appropriate for selecting the second most effective screen. The correct procedure would have been to search for the second most effective screen from the top of the most effective screen (T_1) looking towards both the source and the receiver. The method for quantifying the screen efficiency should be like in the case of the most effective screen except that, if the possible screen is on the source side of the most effective screen the receiver should be replaced by (T_1), and if the possible screen is on the receiver side of the most effective screen the source should be replaced by (T_1).

After the two most effective screens have been identified, the total screen effect is determined in [1] and [2] by calculating the contribution of each of the two screens separately using the equation for a single screen. This equation contains a lower limit of the screen effect of ΔL_S = -20 dB. Since the contribution of the two screens are added, the lower limit will consequently be -40 dB which is an unrealistic screen effect under normal outdoor conditions. Turbulent eddies in the atmosphere over the screen will cause scattering of sound energy into the shadow zone behind the screens reducing the total screen attenuation to not much more than 25 dB independent of the number of screens involved in the propagation.

A further unfortunate complication is coming from a rule described in [2] that the distance between the most and second most effective screen must be at least 20-30 % of the source-receiver propagation distance to include effect of the second most effective screen. In the software SoundPLAN the interpretation of the rule is that if the distance between the two most effective found as described above is less than 25 % of the total distance, the screen effect is calculated using the single screen approach. Another interpretation could have been than the second most effective screen should have been selected among the possible screens with a distance to the most effective screen of more than 25 % of the total distance. However, neither [1] nor [2] contains an unambiguous description of how to solve the problem.

3. Conclusions concerning requirements of a revision

On basis of the analysis of GPM described in Section 2, it can be concluded that the following parts of the method for cases with two or more screens require a revision:

- The method for selecting the most effective screen in the one-screen case is inadequate when based on δ_v.
- The selection of the secondary screen in the two-screen case is based on physical incorrect principles and the selected screen may not necessarily be the second most effective screen.
- The total screen effect in the two-screen case allows a total screen effects of -40 dB for each frequency band. This should be limited to -25 dB.
- The rule of ignoring one of the screens if two screens are too close to each other is ambiguously described and may lead to misinterpretations of how to apply the rule.

Besides, the description of the method for selecting the most and the second most effective screen should be revised to be more straight-forward and unambiguous in general. This can among other things be obtained by introducing the screen effect index which will fill the gap between decisions based on the simple vertical path length difference and on the more complicated screen effect.

To avoid the on-off effect, it is possible to introduce a smooth transition in the rule for ignoring one of the screens when two screens are too close to each other. Based on the description in [2] the natural choice will be a smooth transition from 0% to 50% of the source-receiver distance. However, the numbers given in [2] are rough estimates made in the 1980's where little knowledge was available on how to calculate the two-screen case accurately. Today it would be possible to revise the rule on a much better foundation, but such a revision is beyond the scope of the present work.

4. Proposal for a revised method

In this section a revised procedure is described for calculating the total screen effect ΔL_S of multiple screens in GPM. The procedure will contain a straight-forward and unambiguous approach for finding the two most effective screens based on the screen effect index and a method for calculating the combined effect of the two screens.

4.1 Definition of the screen effect index r_N

Instead of using the transmission path length difference δ or the screen effect ΔL_S as in earlier versions of the General Prediction Method (GPM) the efficiency of the screens is quantified by the screen effect index r_N defined in Eq. (1). r_N contains the combined effect of the vertical transmission path length difference δ_v and the two horizontal path length differences δ_r and δ_l but is less complicated to calculate than ΔL_S.

$$r_N = \frac{1}{20N_v + 3} + \frac{1}{20N_r + 3} + \frac{1}{20N_l + 3} \qquad \textbf{(1)}$$

The screen effect index r_N is a function of the Fresnel numbers N_v, N_r and N_l (calculated as shown in [1] and [2] based on δ_v, δ_r and δ_l) and thus a function of the frequency. Therefore, when r_N is used for ranking the efficiency of screens it is necessary to choose a frequency for the calculation. The frequency is prescribed to be 500 Hz, but the ranking does not depend on the choice. The value of r_N corresponds to an equivalent Fresnel number N_{eq} and path length difference δ_{eq} which could be calculated as shown in Eqs. (2) and (3). But the calculation efficient approach is to work directly with r_N.

$$N_{eq} = \frac{1/r_N - 3}{20} \qquad \textbf{(2)}$$

$$\delta_{eq} = \frac{1/r_N - 3}{20 \cdot 0.0047 f_c} \qquad \textbf{(3)}$$

The calculation of ΔL_S is done for each frequency band with center frequency f_c based on $r_N(f_c)$ according to Eq. (4).

$$\Delta L_S(f_c) = 10 C_h \, log\big(r_N(f_c)\big) \qquad \textbf{(4)}$$

A screen effect ΔL_S exists (a value less than 0) if $N_{eq} > -0.1$. This corresponds to a value of r_N in the range from 1 to 0. Contrary, there is no screen effect ($\Delta L_S = 0$) when $N_{eq} \leq -0.1$ corresponding to $r_N < 0$ or $r_N \geq 1$. The reason for having two intervals in case of r_N instead of one for N_{eq} is that the function $r_N = f(N_{eq})$ has a singularity at $N_{eq} = -0.15$. In the calculation, the easiest way to handle this is to set r_N equal to 1 when $r_N < 0$ or $r_N > 1$.

This way, the screen effect will monotonously depend on the screen effect index r_N. Consequently,

- when $r_N = 1$: $N_{eq} = -0.1$ and $\Delta L_S = 0$
- when $r_N = 1/3$: $N_{eq} = \delta_{eq} = 0$ and $\Delta L_S \approx -5$ dB
- when r_N becomes smaller: ΔL_S will become smaller
- when $r_N > 1/3$, δ_{eq} is negative and when $r_N < 1/3$, δ_{eq} is positive.

4.2 Finding the most effective screen

The most effective screen is determined as the screen with smallest screen effect index r_N calculated based on δ_v, δ_r and δ_l between source and receiver.

If no screens or exactly one screen has a value of r_N less than or equal to 1/3 only the screen with the smallest r_N is considered and hence, the procedure for finding the second most effective screen described in Section 4.3 is not relevant.

When at least one screen has been found with $r_N \leq 1/3$, it is possible to reduce the calculation time of calculating r_N for the remaining screens by using that $\delta_v < 0$ will ensure that $r_N > 1/3$ in which case the screen cannot be the most efficient screen.

If more than one screen has been found with a value of r_N less than or equal to 1/3, the screen with the smallest value of r_N is the most efficient screen and the procedure for finding the second most effective screen described in Section 4.3 must be carried out.

4.3 Finding the second most effective screen

When searching for the second most effective screen only screens found in Section 4.2 with a value of r_N less than or equal to 1/3 is considered a possibility. The reason is that the screen effect index $r_{2,N}$ of the second most effective screen in most cases will be equal or close to 1, if r_N found in Section 4.2 is greater than 1/3 and that calculation time therefore can be saved by using this simplification.

For each screen that may be the second most effective screen the screen effect index $r_{2,N}$ at 500 Hz is used to rank the screens and the second most effective screen is the screen with the smallest value of $r_{2,N}$. The approach depends on whether the screen is on the source or on the receiver side of the most effective screen. If the screen is between the source S and the most effective screen, the same principle for calculating $r_{2,N}$ is used as for the most effective screen except that the receiver R is replaced by the top T_1 of the most effective screen. Alternatively, if the screen is between the most effective screen and the receiver R, it is the source S that is replaced by T_1.

The modified screen effect index $r'_{2,N}$ is calculated by Eq. (5) where $r_{2,N}$ is determined as described above. The variable F is used to modify the screen effect index to model the loss in screen efficiency when a second screen is too close to the most effective screen.

$$r'_{2,N} = r_{2,N}^{F} \qquad \textbf{(5)}$$

The variable F is determined as shown in Eq. (6) where d is the total source-receiver propagation distance and d_{12} is the numerical distance between the considered screen and the most effective screen.

$$F = \begin{cases} \dfrac{d_{12}/d}{0.5} & if\ d_{12} < 0.5d \\ 1 & if\ d_{12} \geq 0.5d \end{cases} \qquad \textbf{(6)}$$

The influence of the variable F in Eq. (5) is that the screen effect ΔL_S corresponds to full effect of $r_{2,N}$ when d_{12} is greater than $0.5d$ and to no effect when d_{12} is equal to 0. The transition between no screen effect and full screen effect is linear in dB.

Comment: The transition used in this revised method is more physical correct than the current implementation in SoundPLAN where full screen effect is obtained above 0.25d and no effect exists below. However, the transition range is still founded on the rough estimate given in [2] by being symmetrical around the 0.25d. The estimate was made in the 1980's where little knowledge was available on how to calculate the effect of two screens. By adjusting the transition range, it may be possible to find a better agreement with today's knowledge. However, such a work has been considered beyond the scope of the present project.

4.4 Calculating the total screen effect

When the most effective screen has been found according to Section 4.2, the screen effect index $r_{1,N}(f_c)$ is calculated at all frequencies and the corresponding screen effect $\Delta L_{S,1}(f_c)$ is determined as shown in Eq. (7).

$$\Delta L_{S,1}(f_c) = 10C_{h,1}\, log\left(r_{1,N}(f_c)\right) \quad \textbf{(7)}$$

When the second most effective screen has been found according to Section 4.3, if any, the screen effect index $r'_{2,N}(f_c)$ is calculated at all frequencies and the corresponding screen effect $\Delta L_{S,2}(f_c)$ is determined as shown in Eq. (8).

$$\Delta L_{S,2}(f_c) = 10C_{h,2}\, log\left(r'_{2,N}(f_c)\right) \quad \textbf{(8)}$$

In the one-screen case the total screen effect $\Delta L_S(f_c) = \Delta L_{S,1}(f_c)$ and in the two-screen case $\Delta L_S(f_c)$ is determined by Eq. (9).

$$\Delta L_S(f_c) = \Delta L_{S,1}(f_c) + \Delta L_{S,2}(f_c) \quad \textbf{(9)}$$

In the two-screen case the lower limit of the total screen effect ΔL_S is -25 dB at each frequency band.

5. Concluding remarks

It is unavoidable that the revised method in some cases may lead to results that deviate from the existing method as implemented into software by SoundPLAN. In most cases, lower noise levels are expected since the major problem has been that the old multiple screens procedure did not always select the most effective screens. However, the smooth transition introduced to consider the effect of two screens being close to each other, and the downward limitation of the total screen effect to -25 dB instead the -40 dB, may create higher noise levels. The former will lead to both lower and higher noise levels around the previous on-off point and the latter is expected to have little practical implication.

It has not been possible to test the revised method in 3D propagation cases. Therefore, it is recommended to wait until the revised method has been implemented into software to finally decide on whether the mode of operation of the revised method is satisfactory. In this connection, it should also be tested how the revised method is working on previously identified cases with problematic behavior of the multiple screens procedure.

6. References

[1] J. Kragh et al.: *Environmental noise from industrial plants. General prediction method*, Danish Acoustical Laboratory, Report no. 32, 1982.

[2] Vejledning fra Miljøstyrelsen nr. 5/1993: *Beregning af ekstern støj fra virksomheder* (Guideline from Danish EPA).