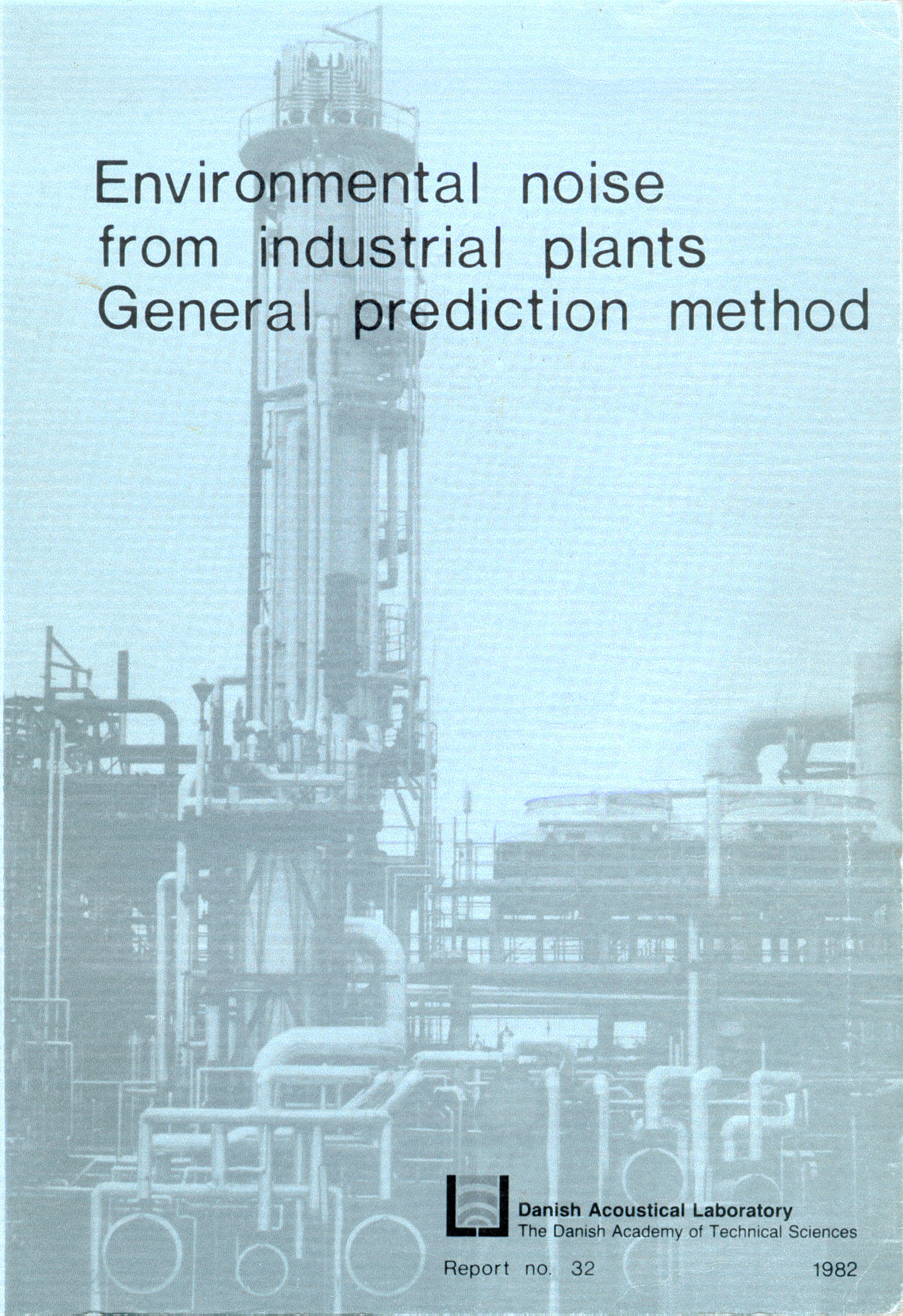
Environmental noise from industrial plants General prediction method



Danish Acoustical Laboratory
The Danish Academy of Technical Sciences

Report no. 32

1982

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TECHNICAL REPORT

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Summary

This report describes procedures to be used for the prediction of noise immission in areas adjacent to industrial plants. The proposed method has been developed as the central part of a joint Nordic research project on environmental noise from industry, coordinated by NORDFORSK. Methods for source data acquisition and immission measurements are described in other reports worked out within this project.

The prediction method is an octave band method (63-8000 Hz). The real noise sources at an industrial plant are represented by equivalent monopole sources. Transmission path attenuation is estimated by means of additive corrections for spherical divergence, air absorption, reflections from vertical surfaces, screening by one or more screens, vegetation, ground effect, and in-plant scattering. The predicted immission point sound pressure levels correspond to energy mean values within the meteorological conditions specified for immission measurements (downwind).

The accuracy of the predicted noise immission has yet to be verified. However, some values of expected L_{Aeq} standard deviations have been given in section 1.

The layout of industrial plants vary considerably. Even if the prediction method is intended to be a general method, a successful prediction depends on qualified engineering judgements. To describe all possible procedures in detail would leave the method impracticable. The user should have some knowledge of and experience in acoustics.

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PREFACE

The prediction method described in this report has been developed as a part of a comprehensive system of methods for the prediction and measurement of noise immission in areas adjacent to industrial plants. The system consists of methods for

- Emission measurements and -prediction
- Transmission path attenuation prediction
- Immission measurements

The noise immission is predicted as a function of measured acoustical data for the main noise sources and predicted attenuations along the propagation path. The system has been designed to yield the same predicted and directly measured noise immission.

Coordination of the work on different parts of the system has been sponsored by Nordforsk. Updated list of references to relevant reports can be obtained from Nordforsk, Box 5103, S-102 43 Stockholm, Sweden.

This part - the general prediction method - has been sponsored by the National Environmental Protection Agencies in

Denmark:	Miljøstyrelsen, contract no. M83421-14
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Sweden:	Statens Naturvårdsverk, contracts nos. 7-574/78 and 5322110-7.

Follow-up projects with the purpose of system validity verification and evaluation of overall system precision will be carried out in 1982/83.

C O N T E N T S

APPENDICES:

0. SUMMARY

This report describes procedures to be used for the prediction of noise immission in areas adjacent to industrial plants. Methods for source data acquisition are described in other reports worked out within the Nordforsk frame project.

Basically the prediction method is an octave band method. It is assumed that each real noise source at an industrial plant can be represented by an equivalent monopole source. Transmission path attenuation is estimated by means of additive corrections for spherical divergence, air absorption, reflections from vertical surfaces, screening, vegetation, ground effect, and in-plant scattering. These attenuation estimates correspond to energy mean values within the set of meteorological conditions specified for immission measurements, i.e. basically moderate downwind or slight temperature inversion. The accuracy has yet to be verified in follow-up projects.

Note 1: The energy mean value of noise immission under these meteorological conditions is higher than the long term (e.g. one year) averaged noise immission.

Note 2: Results of individual noise immission measurements will scatter around the predicted energy mean value.

The layout of industrial plants vary considerably. Therefore no typical examples can be presented. The basis for a successful prediction is the sound judgement of the engineer performing the analysis.

1. INTRODUCTION

1.1 General

A method for the prediction of noise immission is important to industry, to consulting engineers, and to environmental authorities when a new industry is being planned or when planning expansion, changed operation, or noise reduction at an existing plant. Prediction of noise immission may also prove useful in situations when e.g. background noise prevents reliable immission measurements.

Very often a method for overall A-weighted equivalent continuous sound pressure level, L_{Aeq}, predictions is wanted. This present method - being a *general* method - is an octave band method. If preliminary L_{Aeq} predictions are wanted e.g. at an early planning stage, the user can make engineering judgements as to dominating octave bands or the like.

A few draft versions of this present method has been circulated to experts in the Nordic countries, and the method has been discussed among others at a seminar organized by Nordforsk in Røros, Norway, September 1981, ref. [1]. Suggestions from this seminar have been included in the present method, which is the final result of part D.1 of the Nordforsk frame project on environmental noise from industry.

The method is to a wide extent based on a recently published Dutch method (ref. [2]) which represents an elaboration and refinement of an earlier German draft method (ref. [3]). Changes in some procedures have been introduced to ensure compatibility in the system developed within the Nordforsk frame project.

1.2 Precision

It has been essential throughout the Nordforsk project to obtain a system of methods yielding the same results whether the noise immission is predicted or measured directly. Overall system precision has yet to be determined among others based on results of test projects. Therefore only some qualitative considerations can be given at present.

The precision in source sound power data is affected by variations in working conditions and weather, by the final number of microphone positions, irregularities in measurement environment, etc. In general the precision in source data acquired using a recommended method has been estimated in the relevant reports to correspond to ISO survey precision. Variations due to varying working conditions have to be evaluated in each situation.

The real noise source is substituted by an equivalent monopole, the height of which is difficult to determine. Very often the source height has to be estimated roughly. This introduces an uncertainty in transmission path transfer function.

Transmission path attenuation is known to fluctuate, mainly due to variations in meteorological conditions. The magnitude of these variations depend on a number of parameters: frequency, source and immission point height, distance from source to immission point and topography - including overall shape and details in structure of ground surface - buildings, screens, and vegetation, etc. Overall system reproducibility has been aimed at by defining a set of meteorological conditions, within the frame of which the meteorologically induced fluctuations will be reasonably limited, i.e. moderate downwind or slight temperature inversion conditions (ref. [4]). Predicted attenuations correspond to energy mean values within this meteorological frame. This attenuation is less than a long-term equivalent value. Results of "individual" measurements (samples) of noise immission (from stationary sources) are expected to vary around this mean value.

The order of magnitude of expected L_{Aeq} standard deviations is:

- 5 to 10 dB for a single source close to the ground radiating narrow band noise in the frequency range around 250 or 500 Hz. High values are expected in immission points close to the ground and far from the source.

- 1 to 3 dB for groups of broadband sources at distances less than 500 m, with high values at immission points approximately 2 m above the ground and low values at immission points more than 5 m above the ground.

- Less than 1 dB for groups of many broadband sources located relatively high above the ground in immission points near the source or more than 5 m above the ground.

Note: Very little information is available concerning transmission over long distances, e.g. > 1 km. Ground effect might decrease and special meteorological effects may occur (focusing).

2. LAYOUT

The basic layout of the prediction method is illustrated in Figures 2.1-3 and partly summarized in Figure 2.4. A further elaboration is given in Figures 2.5-6 and in the sections stated in Figure 2.4.

The prediction method uses source data and topographical data as inputs. Based on these data the contributions to immission point sound pressure levels are calculated for each transmission path from each source. Calculations are made in octave bands with centre frequencies 63-8000 Hz.

2.1 Source

Each real noise source is represented by an equivalent monopole source as illustrated in Figure 2.1. In this simplified figure the noise emission from the industry is due to j = 4 different noise sources. From each of these sources only one transmission path to the immission point exists. The ground effect is included in each transmission path.

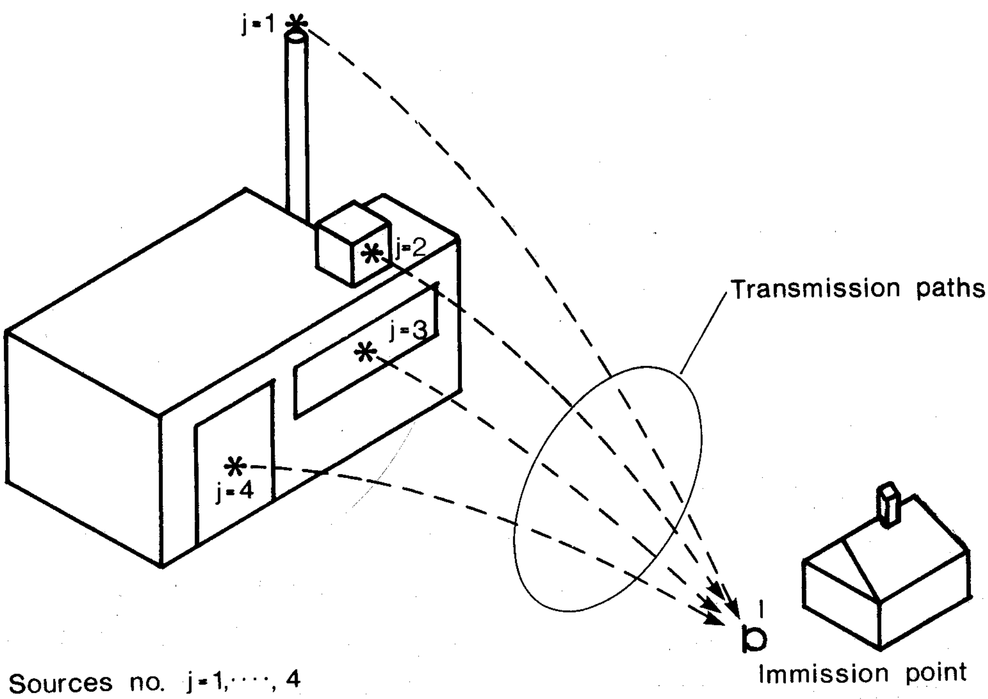

Figure 2.1 Illustration of monopole representation of real sources, cf text.

Each of the equivalent monopoles is characterized by its position and its strength, i.e. the immission relevant source sound power level, $L_W(\Phi)$. Φ is the angle between a reference direction and the direction of the transmission path from the source S to the immission point I, cf Figure 2.2. Methods for acquiring source data are described in other reports. Sound power data for each relevant working condition should be available in octave bands, i.e. an octave band spectrum $L_W(\Phi)_i$, i being the octave band number.

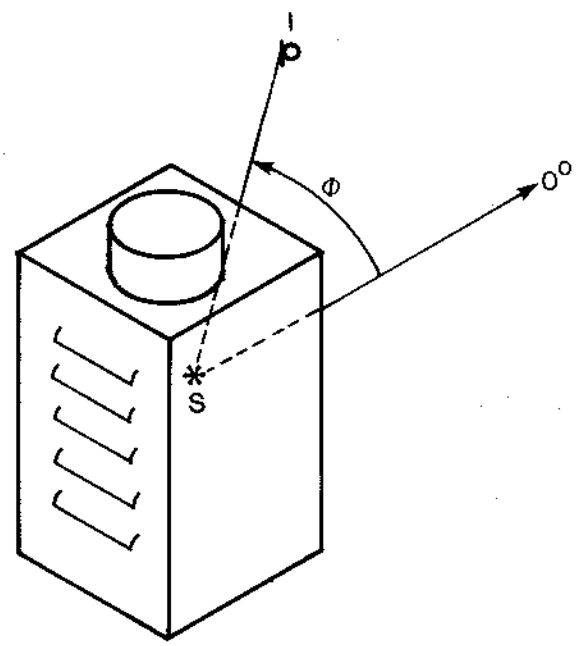

Figure 2.2 Illustration. Source sound power varies with direction to immission point, cf text.

2.2 Transmission Path

For each source the contribution to the immission point sound pressure level is calculated for each transmission path from source to immission point. In Figure 2.3 a simple illustration is shown. From the source S_j to the immission point I two transmission paths are shown: no. t = 1 via the screen and no. t = 2 via reflection from the facade of a building. Sound energy arriving from each of these paths has to be added to obtain the total sound pressure level at the immission point.

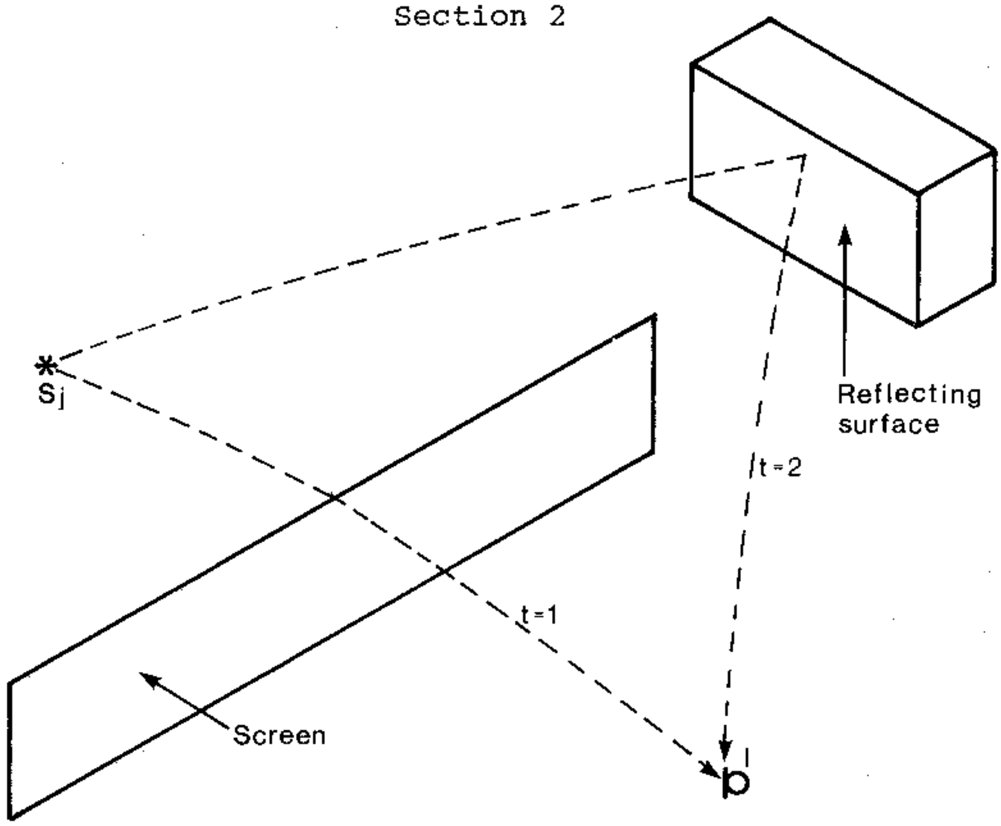

Figure 2.3 Illustration. Two transmission paths.

For each transmission path a transfer function, $(\Sigma\Delta L)_{ti}$, is calculated. $(\Sigma\Delta L)_t$ is a summation of corrections due to events along the transmission path no. t. Index i indicates octave band number since ΔL in general is frequency dependent.

2.3 Immission Point

Octave band sound energy contributions arriving at the immission point are calculated by adding each source sound power level and corresponding transmission path transfer function value, equation (2.1). By adding these contributions on an energy basis the immission point octave band frequency spectrum is obtained, equation (2.2). After applying IEC curve A corrections the corrected octave band levels are added on an energy basis and thus the A-weighted immission point sound pressure level is obtained, equation (2.3).

Note 1: The A-correction may be applied to source sound power levels instead.

Note 2: The IEC curve A octave band corrections are given in Appendix A.

INPUT: SOURCE DATA

Description: one or more monopole sources

For each monopole source (no. j) data required are the source position and source sound power level $L_W(\Phi_t)_i$ per 1/1 octave band (no. i) per direction Φ_t for relevant source working conditions.

Procedures to acquire these data are described in refs. [5-8] . Eventually, a data base may be established.

SECTION 3

↓

TRANSMISSION PATH TRANSFER FUNCTION

For each source (no. j) one transfer function for each transmission path (no. t) to each immission point is calculated.

I.e. add correction to $L_W(\Phi_t)_i$ per 1/1 octave band no. i and transmission path no. t.

SECTION 4

↓

IMMISSION POINT SOUND PRESSURE LEVEL

In each immission point:

Source power corrected with transfer function for each transmission path give source contribution to immission point sound pressure level per 1/1 octave band, 63 Hz - 8 kHz.

Energy summation yields total 1/1 octave band frequency spectrum at immission point.

A-correction* and energy summation of A-corrected 1/1 octave band sound pressure levels yield A-weighted sound pressure level at immission point.

THIS SECTION

* A-correction of sound power levels instead is optional.

Figure 2.4 Summary of basic layout of the prediction method.

IMMISSION = SOURCE POWER + TRANSFER FUNCTION:

$$\underbrace{(L_p)_{tij}} = \underbrace{L_W(\Phi_t)_{ij}} + \underbrace{(\Sigma\Delta L)_{tij}} \qquad (2.1)$$

$(L_p)_{tij}$ = Sound pressure level contribution via transmission path no. t from source no. j [dB re 20 μPa] in 1/1 octave band no. i at immission point.

$L_W(\Phi_t)_{ij}$ = Sound power level [dB re 1 pW] in direction Φ_t of transmission path no. t in 1/1 octave band no. i for source no. j.

$(\Sigma\Delta L)_{tij}$ = Transfer function value [dB] in 1/1 octave band no. i for transmission path no. t between source no. j and immission point.

This value is determined as the sum of a number of corrections taking the influence of various transmission phenomena into account.

IMMISSION POINT 1/1 OCTAVE BAND FREQUENCY SPECTRUM:

$$(L_p)_i = 10\,\lg \left\{ \sum_{t=1}^{m} \sum_{j=1}^{n} 10^{(L_p)_{tij}/10} \right\} \qquad (2.2)$$

$(L_p)_i$ = Total sound pressure level in 1/1 octave band no. i at immission point calculated by summation of contributions via transmission paths nos. t = 1, ..., m from sources nos. j = 1, ..., n.

n = Total number of sources contributing to $(L_p)_i$ (including mirror sources).

m = Total number of transmission paths from source no. j to immission point.

OVERALL A-WEIGHTED SOUND PRESSURE LEVEL:

$$L_{pA} = 10\,\lg \left\{ \sum_{i=1}^{8} 10^{\frac{(L_p)_i + \Delta L_{Ai}}{10}} \right\} \qquad (2.3)$$

L_{pA} = A-weighted sound pressure level at immission point.

ΔL_{Ai} = Correction corresponding to IEC curve A, in 1/1 octave band no. i.

If all sources are stationary or if all contributions to $(L_p)_i$ before summation are normalized* to be energy-equivalent contributions in the time interval considered, L_{pA} is equal to L_{Aeq}, i.e. the equivalent continuous A-weighted sound pressure level.

* Cf section 3.

Figure 2.5 Summary of procedures for calculations.

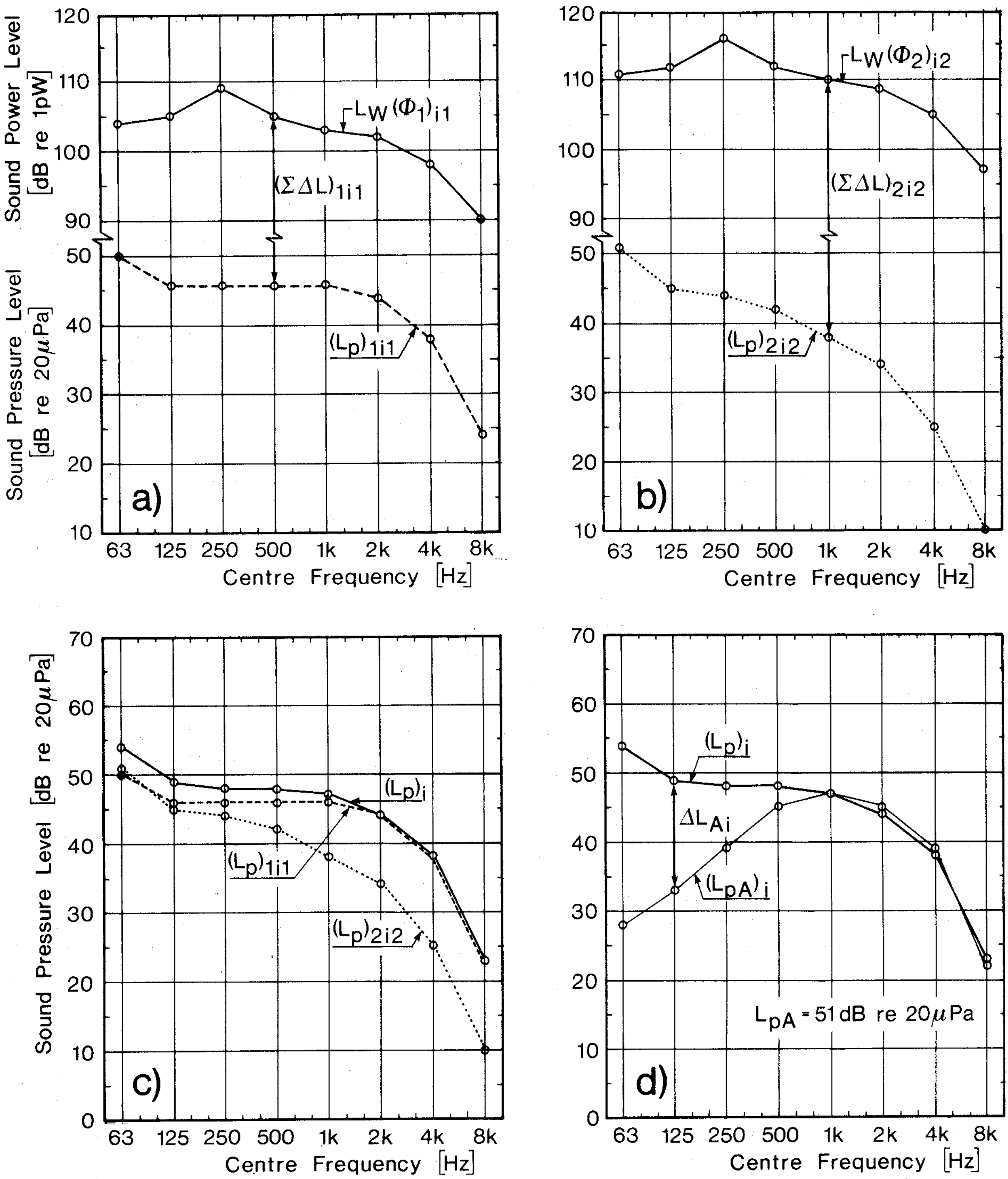

Figure 2.6 Graphical illustration of calculation (cf Example 4 in Appendix F and text p. 17) of L_{pA} in the immission point when two sources contribute to L_{pA} via one transmission path each.

Figure 2.6:

a) Sound power level $L_W(\Phi_1)_{i1}$ in octave bands in direction Φ_1, from source S_1 (j = 1), transfer function $(\Sigma\Delta L)_{1i1}$ for transmission path no. t = 1, in direction Φ_1, and contribution $(L_p)_{1i1}$ to immission point sound pressure level arriving via transmission path no. 1.

b) Same as a) but for transmission path no. t = 2 in direction Φ_2, from source S_2 (j = 2).

c) Contributions to immission point sound pressure level $(L_p)_{tij}$ from sources S_1 and S_2 via transmission paths nos. t = 1 and t = 2, respectively, and total $(L_p)_i$.

d) A-correction of $(L_p)_i$ and overall A-weighted sound pressure level (L_{pA}) at immission point.

3. SOURCE DESCRIPTION

3.1 Principles

As a basis of this prediction method each source should be represented by its "equivalent monopole". This is defined as a hypothetical point source which generates - if substituting the real source - the same sound pressure level as the real source.

The strength of an equivalent monopole is defined as the *immission relevant* source sound power level $L_W(\Phi)$ per 1/1 octave band. $L_W(\Phi)$ will generally depend on the direction (indicated by the angle Φ) of the transmission path from the source to the immission point considered.

Note 1: The expression "immission relevant" indicates that $L_W(\Phi)$ is not in general the same as the total sound power level of the source. Only part of the emitted sound energy reaches the immission point, due to sound propagation conditions. Thus only the emission in a horizontal plane is considered in the methods in refs. [5-6]. $L_W(\Phi)$ is denominated the *horizontal directive sound power level.*

Note 2: If the source working conditions are time dependent, an energy equivalent value of $L_W(\Phi)$ may be calculated for the time period considered.

If the sound immission from an extended source is to be predicted, the extended source or parts of the extended source must be represented by one or more monopoles, cf section 3.2.

Methods for acquiring data on source position and source strength are described in detail e.g. in refs. [5-8]. Data furnished by equipment manufacturers may be useful in some cases. During the Nordforsk project it has been considered to create a joint Nordic data base. Such a data base may be useful in the future.

Emission measurements may be regarded as "reciprocal" procedures to those involved in this prediction method. Based on results of sound pressure level measurements in prescribed positions in the proximity of the source $L_W(\Phi)$ can be estimated. It has to be decided in each case where to place the "transition" (boundary) between source and transmission path, respectively (i.e. for instance whether to include the effects of reflecting obstacles close to the source in the source emission or in the transmission path transfer function).

The value of $L_W(\Phi)$ is determined as

$$L_W(\Phi) = L_W + \Delta L_\Phi \qquad (3.1.1)$$

$L_W(\Phi)$ = horizontal directive or immission relevant sound power level, in direction Φ, [dB re 1 pW].

L_W = horizontal sound power level, averaged over all directions, [dB re 1 pW].

ΔL_Φ = correction for directional effects in a horizontal plane, [dB].

Note 1: Equation (3.1.1) has been used in ref. [5]. ΔL_Φ has been denominated horizontal directivity index and assigned the symbol DI_i, [ibid. p. 33-34].*

Note 2: In the long distance method of ref. [6] ISO definitions have been preferred. Therefore the horizontal directivity index DI(hor) [ibid. p. 27] has been defined according to ISO 3744. This implies totally sound reflecting ground surface and vertical surfaces, if any, in the proximity of the source. Directly transmitted and reflected sound energy is considered incoherent.

When source data have been obtained by means of the long distance method of ref. [6], ΔL_Φ to be used in equation (3.1.1) is

$$\Delta L_\Phi = DI(hor) \div 3n \qquad (3.1.2)$$

The value of n is the number of reflecting surfaces near the source, including the ground, i.e.

$n = 1$ near the ground in a semifree field

$n = 2$ near the ground at a wall

$n = 3$ near the ground in a corner

(cf ref. [6] p. 15 and 27).

Note 3: If the short distance method of ref. [6] is used, directional effects cannot be taken into account. Therefore $L_W(\Phi)$ has to be assumed equal to L_W, i.e. ΔL_Φ = 0 dB. This implies less accurate predictions in some cases.

A special problem which has to be considered is the effect of time varying source working conditions (e.g. for intermittently working sources or the like). Assuming that the purpose of

* Final version not yet published.

the prediction is to estimate L_{Aeq} for a specified reference time interval (e.g. 8 h, 1 h , etc.), an energy equivalent source sound power level for this reference time interval should be used as an input to the prediction procedure.

3.2 Guidelines for the Source Description

In general a separate prediction of immission point sound pressure level contributions for each individual source would provide the most flexible system and would ideally yield the highest degree of accuracy.

It will, however, in practice often be useful to group as many individual sources as possible, thereby reducing the amount of calculations needed for the prediction.

Note: An initial judgement often enables minor contributions from each of relatively many individual sources to be neglected without any significant loss of prediction accuracy.

A group of uniform and approximately equally positioned sources can be represented by one equivalent monopole, provided the distance d from the group centre S to the immission point I is greater than the largest group dimension ℓ cf Figure 3.2.1.

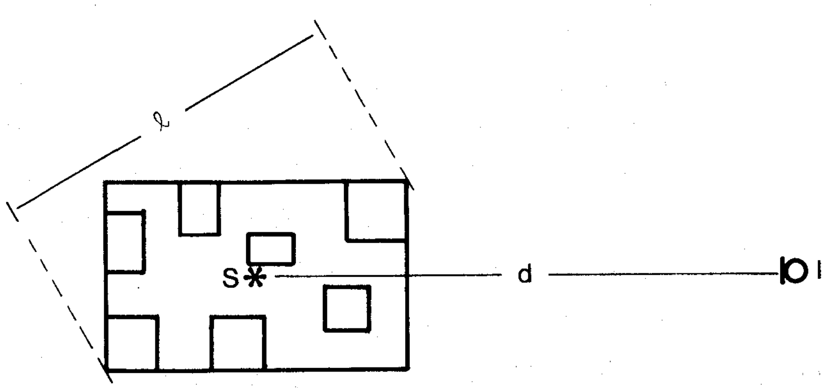

Figure 3.2.1 Plan view. A group of uniform sources can be represented by one equivalent monopole at S, if $d > \ell$.

Note 1: A criterion to be used for evaluating the degree of uniformity of a group of sources would be that the contribution to the immission point sound pressure level should be approximately equal for all sources. An evaluation has to be made in each separate case.

Note 2: The source strength of an equivalent monopole representing a group of sources will not in general be equal to the sum of the strengths of the individual sources. This would only be the case (approximately) in situations with no reflections, diffractions, or scattering influencing sound propagation within the group.

In cases where d is less than ℓ the group has to be divided into subgroups each fulfilling the condition in Figure 3.2.1, or calculations have to be carried out for each separate source.

Sources with strength or/and height differing essentially from the data for the remainder of sources involved always have to be dealt with separately. The same applies in cases where transmission path properties are not uniform. This could be caused by differences in screening and ground effect, etc.

A special type of extended sources is large uniformly sound radiating surfaces, e.g. walls of industrial buildings, cf Figure 3.2.2 and ref. [8].

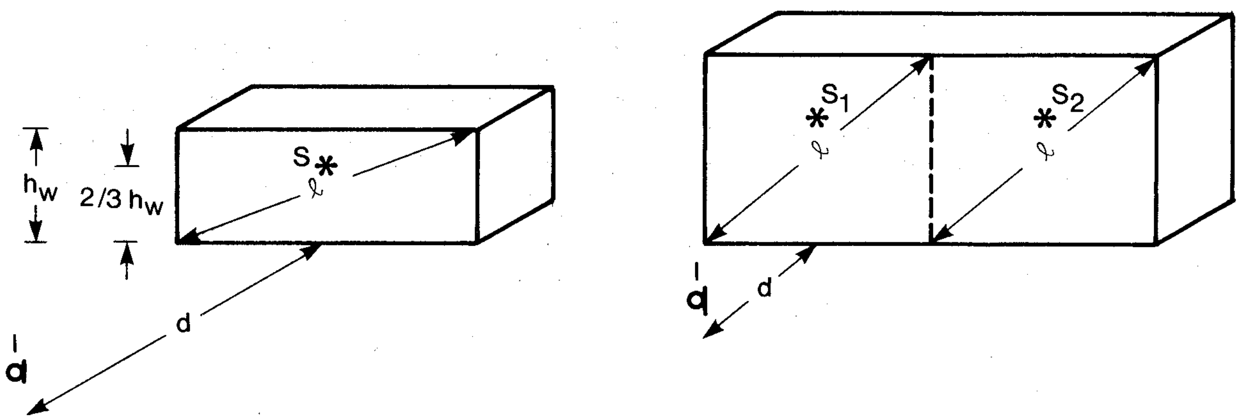

Figure 3.2.2 Division of sound radiating surface into parts, each represented by an equivalent monopole, to fulfil the condition d > ℓ.

In general walls can be represented by one equivalent monopole. This monopole should be placed at the middle of the wall base line, two thirds up. The condition d > ℓ should be fulfilled. If this is not the case, the wall has to be divided into smaller parts each fulfilling the condition d > ℓ and each represented by one equivalent monopole.

In cases where individual parts of the wall (windows, doors, fan outlets, etc.) radiate significantly more sound energy than the remainder of the wall, these parts should be dealt with separately, each part being represented by its equivalent monopole(s). The same applies when significant variations in transmission path properties occur.

Another type of extended source is a line source (e.g. a pipe line). This can be represented by one equivalent monopole if the condition of Figure 3.2.1 is fulfilled - in this case ℓ being the length of the source - and if the transmission path properties from all sections of the source are uniform. If this is not the case, the source has to be divided into sections, each being represented by its own equivalent monopole. Some information on noise radiation from pipe lines can be found e.g. in ref. [7].

Note: In situations when an extended source is partly screened, serious problems of discontinuity might be introduced if the source is represented by one equivalent monopole. This effect is reduced by division of the extended source into a screened and an unscreened part, cf ref. [8] and Examples 3-4 in Appendix F.

This also applies in situations when the sound energy radiated from a part of an extended source is transmitted to the immission point via reflecting obstacles.

4. TRANSMISSION PATH TRANSFER FUNCTION

4.1 Correction Terms

The transmission path transfer function is determined by adding a number of corrections, in general designated by the symbol ΔL. An index attached indicates the cause of the correction considered. The corrections used in this prediction method are summarized in Table 4.1.1.

The transmission path transfer function, $\Sigma\Delta L$, in octave bands is determined according to equation (4.1.1).

$$\Sigma\Delta L = \Delta L_d + \Delta L_a + \Delta L_r + \Delta L_s + \Delta L_v + \Delta L_i + \Delta L_g \qquad (4.1.1)$$

Symbol	Correction taking into account the effect of	Description in section
ΔL_d	divergence	4.2
ΔL_a	air absorption	4.3
ΔL_r	reflecting obstacles	4.4
ΔL_s	screening	4.5
ΔL_v	vegetation	4.6
ΔL_i	internal (in plant) scattering	Appendix D
ΔL_g	ground	4.7

Table 4.1.1 Survey of correction terms.

As already mentioned in section 1 the correction terms are aplicable to energy mean values obtained within the meteorological conditions specified for immission measurements, cf ref. [4].

4.2 Divergence, ΔL_d

ΔL_d is a correction which takes into account the spherical divergence of the sound energy radiated by the equivalent monopole. For a loss free and undisturbed propagation in homogeneous and still air ΔL_d is ÷6 dB per doubling of the distance R from the source to the immission point. ΔL_d is frequency independent and always less than zero. With the parameters illustrated in Figure 4.2.1 ΔL_d can be calculated using equation (4.2.1).

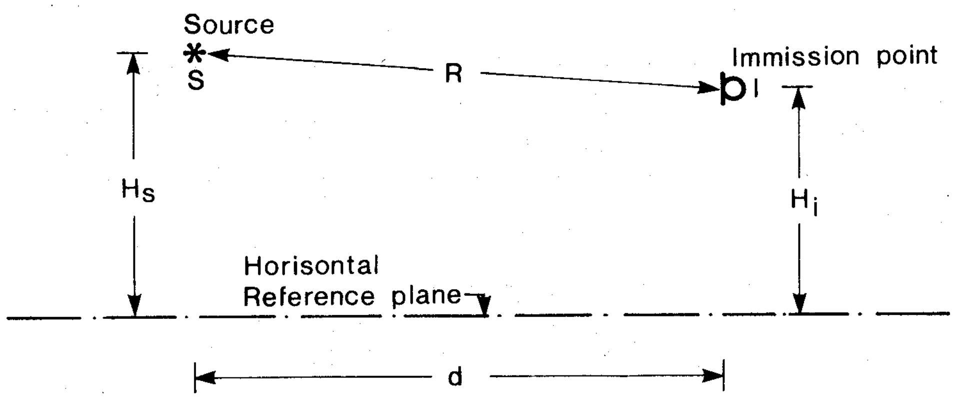

Figure 4.2.1 Sketch showing geometry. Cross section.

$$\Delta L_d = -10 \lg 4\pi R^2 \quad [dB] \qquad (4.2.1)$$

$$R^2 = (d^2 + (H_s - H_i)^2) \quad [m^2]$$

ΔL_d = correction due to divergence, [dB]

R = distance between source S and immission point I, [m]

d = horizontal projection of R, [m]

H_s = height of source above horizontal reference plane, [m]

H_i = height of immission point above horizontal reference plane, [m]

The horizontal reference plane can be placed at any arbitrary level.

Note: Very often $d \gg (H_s - H_i)$. In this case $\Delta L_d \approx -20 \lg d - 11$ [dB].

4.3 Air Absorption, ΔL_a

ΔL_a is a correction taking into account the transmission losses due to energy dissipation and molecular relaxation in air. ΔL_a is a function of the frequency, and its value depends upon the humidity, the static pressure, and the temperature of the air, ref. [9]. ΔL_a is always less than zero.

For planning purposes it it recommended to assume a relative humidity RH = 70% and a temperature of 15°C. The influence of the static pressure may be neglected. Under these conditions ΔL_a can be calculated using equation (4.3.1). If in special situations other humidity or temperature conditions are of interest, data from Appendix B may be used.

$$\Delta L_a = -\alpha_a \cdot R \quad [dB] \qquad (4.3.1)$$

α_a = attenuation coefficient to be found in Table 4.3.1, [dB/m]

R = transmission path length, [m]

1/1 octave f_c [Hz]	63	125	250	500	1000	2000	4000	8000
α_a [dB/m]	0.000	0.000	0.001	0.002	0.004	0.007	0.017	0.056

Table 4.3.1 Attenuation coefficient for 1/1 octave bands with centre frequency f_c. 15°C, 70% RH.

Note 1: The values of α_a have been calculated according to ref. [9] for frequencies corresponding to the centre frequency of the lowest 1/3 octave band (i.e. $f_c/\sqrt[3]{2}$) in each 1/1 octave band.

Note 2: When R < 200 m ΔL_a can be set equal to zero without any significant loss in precision except for high frequency dominated sources, e.g. valves and steam outlets.

4.4 Reflecting Obstacles, ΔL_r

4.4.1 Principle

In this prediction method the effects of sound reflections from obstacles are treated by simple acoustical mirror considerations. The principle of these has been illustrated in Figure 4.4.1: The angle between the direction of the incident sound field and the normal to the reflecting surface is equal to the angle between this normal and the direction of the reflected sound field. The sound pressure level at the immission point can be considered to be built up by two uncorrelated contributions arriving via two transmission paths. The sound pressure level at the immission point can be calculated by adding on an energy basis the contributions from the real source S and the mirror source S_m, respectively.

Note 1: Very often a reflecting surface (facade) is present close to the immission point. In ref. [4] further information can be found concerning the special circumstances close to small reflecting facades.

Note 2: Usually it is sufficient to consider transmission paths involving one or two reflections. This, however, has to be analysed in each separate case.

Note 3: The effect of multiple reflections, e.g. occurring when the transmission path passes through built up residential areas, might be predicted analogous to ΔL_v or ΔL_i, provided appropriate attenuation coefficient values were available. This is not the case, however.

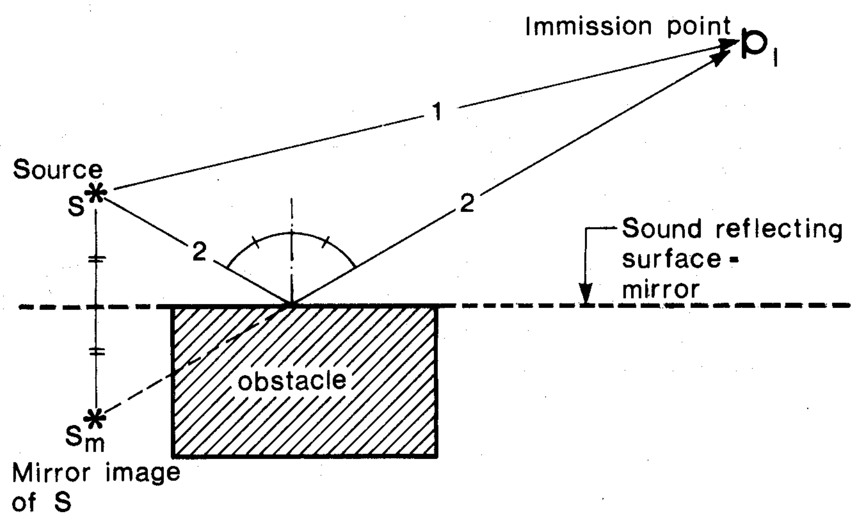

Figure 4.4.1 Plan showing transmission paths between S and I. Note the mirror source S_m.

Path 1: directly
Path 2: via reflection from building facade

In the guidelines below a correction ΔL_r is given. This can - under the conditions specified - be added to the transmission path transfer function for path no. 1 (Figure 4.4.1) to account for the contribution from path no. 2. ΔL_r is always greater than or equal to zero.

4.4.2 Guidelines

Case A

If the properties of transmission paths no. 1 and 2 (Figure 4.4.1) are approximately equal, and if the conditions specified in Table 4.4.1 are all fulfilled, the mirror source is omitted, and instead a correction ΔL_r calculated by means of equation (4.4.1) is added to the transfer function of transmission path no. 1.

$$\Delta L_r = 10 \lg (1 + \rho) \quad [\mathrm{dB}] \qquad (4.4.1)$$

ρ is the (energy) reflection coefficient of the surface of the reflecting obstacle. In the absence of actual data the value of ρ can be taken from Table 4.4.2.

Note: The term "equal transmission path properties" includes equal values of ΔL_Φ, i.e. $L_W(\Phi') \approx L_W(\Phi)$, cf Figure 4.4.2.

Case B

If there is an essential difference between the transfer functions of transmission paths nos. 1 and 2 (Figure 4.4.1), and the conditions specified in Table 4.4.1 are all fulfilled, a mirror source S_m has to be introduced. The mirror source sound power level $L_W(\Phi)_m$ is determined by equation (4.4.2).

$$L_W(\Phi)_m = L_W(\Phi') + 10 \lg \rho \quad [\mathrm{dB\ re\ 1\ pW}] \qquad (4.4.2)$$

$L_W(\Phi')$ is the sound power level of the source in direction Φ', cf Figure 4.4.2, [dB re 1 pW].

ρ is the (energy) reflection coefficient of the surface of the reflecting obstacle. If no actual information is available on the value of ρ, reference can be made to Table 4.4.2, [-].

Note 1: Even in situations (Cases B and C above) when one or more of the conditions specified in Table 4.4.1 are not fulfilled, the contribution to the immission point sound pressure level from reflected sound energy might be essential. This could e.g. be the case if transmission path no. 1 was screened while transmission path no. 2 was unscreened (cf Figure 2.3). In such situations a judgement has to be made as to the mirror source strength.

Note 2: In equation (4.4.2) the index m in $L_W(\Phi)_m$ indicates mirror source, while the mark on Φ in $L_W(\Phi')$ indicates that source directivity (if any) has to be taken into account, i.e. $L_W(\Phi')$ is the source sound power level in direction Φ', cf Figure 4.4.2.

Note 3: The effect of reflections from the ground is included in ΔL_g.

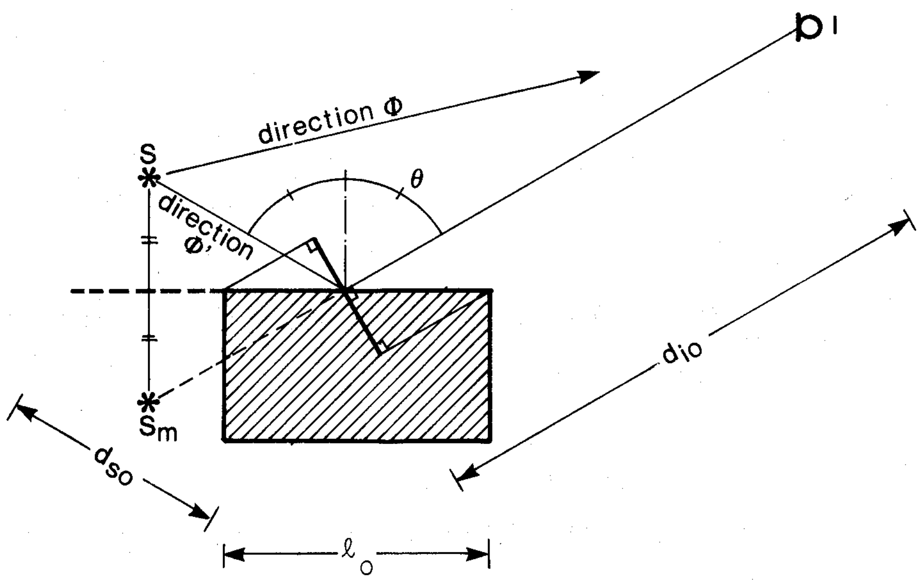

Figure 4.4.2 Illustration of some of the parameters included in conditions nos. 1-5 in Table 4.4.1.

Condition No.	Specification (cf Figure 4.4.2)
1	The reflecting obstacle should be "solid", plane, and acoustically hard (i.e. acoustically "transparent" obstacles as for instance rows of trees and open process plant installations etc. are excluded).
2	The horizontal dimension of the reflecting obstacle measured perpendicular to the transmission path should be greater than the wavelength, λ_c, i.e. $\ell_o \cos \Theta > \lambda_c$ (4.4.3) ℓ_o is the horizontal dimension of the reflecting obstacle. Θ is the angle of incidence.
3	The height H_o of the reflecting obstacle above the horizontal reference plane should fulfil at least one of the following criteria: $H_o > H_s + \frac{1}{16} d_{so}$ $H_o > H_i + \frac{1}{16} d_{io}$ (4.4.6-7) d_{so} is the horizontal distance source-obstacle. d_{io} is the horizontal distance immission point -obstacle. H_s is the source height above the horizontal reference plane. H_i is the height of the immission point above the horizontal plane (cf also Figure 4.5.5).
4	The angle of incidence, Θ, should be less than 85^o.
5	The reflection should take place at least at a distance λ_c from the edge of the obstacle.

Table 4.4.1 Conditions 1-5 which should all be fulfilled before a mirror source has to be introduced.

Reflecting obstacle	ρ
Plane and acoustically hard wall	1
Building with windows and small irregularities	0.8
Buildings with openings in the order of magnitude of 50% of the wall area, "dense" installations of the type pipes or the like	0.4
Acoustically hard cylinder (container, silo)	$\frac{\ell_o \cdot \sin \psi/2}{2 \cdot d_{sc}}$

ℓ_o = cylinder diameter

d_{sc} = distance from source to middle C of cylinder

$d_{sc} << d$

ψ = supplement to the angle between the line SC and the line IC

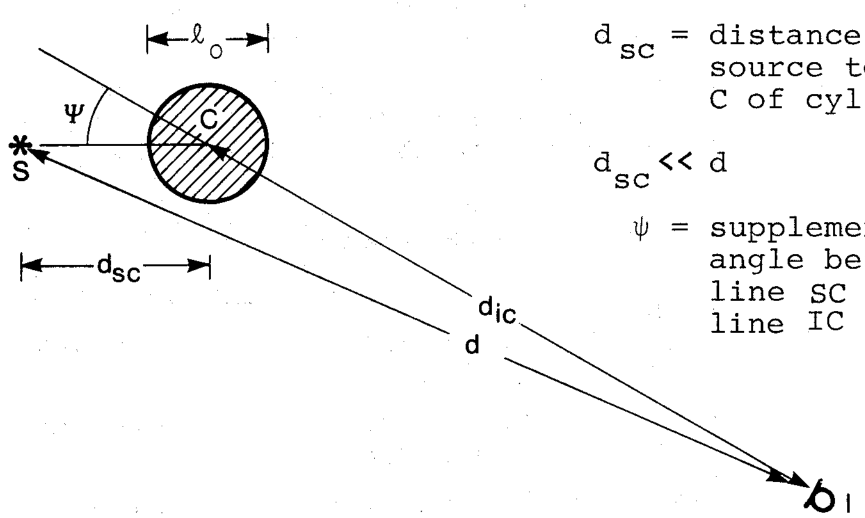

Table 4.4.2 Recommended values of the (energy) reflection coefficient ρ to be used in the absence of actual acoustical data.

Note: In general ρ is frequency dependent. Very little quantitative data exist, however. The values in Table 4.4.2 are recommended approximative values.

4.5 Screening, ΔL_s

4.5.1 General

The general principle in calculating the screening correction, ΔL_s, is to identify all screening obstacles between source and immission point. Each obstacle is represented by a regularly shaped, thin screen. The calculation procedure depends on the number of screens present. Usually only one screen is taken into account. ΔL_s is then calculated according to section 4.5.4. If more than one screen are present, the procedure in Appendix C should be applied.

In section 4.5.2 some of the conditions to be fulfilled before a screen should be considered effective are set up.

In section 4.5.3 guidelines for the transformation of irregularly shaped screening obstacles into their schematical representation are given.

A vertical plane V through the source and immission point is considered (cf Figure 4.5.3). The procedure for the calculation of the correction ΔL_s due to screening depends on the number of screen representations which intersect this plane, cf Figure 4.5.1.

Note 1: Extended obstacles close to the plane V would affect the sound propagation. This diffraction effect is, however, neglected here.

Note 2: Extended sources have to be divided into a screened and an unscreened part to avoid discontinuity (cf section 3.2 and Appendix F).

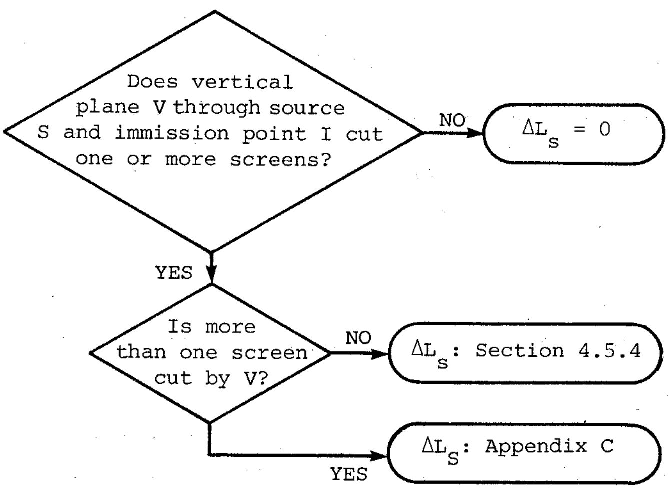

Figure 4.5.1 Simple flow diagram illustrating the choice of procedure for calculating the correction ΔL_s due to screening.

4.5.2 Screen Qualification Guidelines

If all of the conditions 1-3 specified in Table 4.5.1 are fulfilled, ΔL_s is less than or equal to zero. If one or more of these conditions are not fulfilled, ΔL_s may be set equal to zero.

Condition No.	Specification
1	The mass of the screen should exceed 10 kg/m^2.
2	There should be no slits or openings in the structure (i.e. process plant installations, rows of trees, etc. are excluded).
3	The horizontal dimension perpendicular to the line between the source and the immission point (cf Figure 4.5.2) should be greater than the wavelength, i.e. $s_\ell + s_r > \lambda_c$ (4.5.1)

Table 4.5.1 Conditions 1-3 which are all to be fulfilled to take values of $\Delta L_s < 0$ into account.

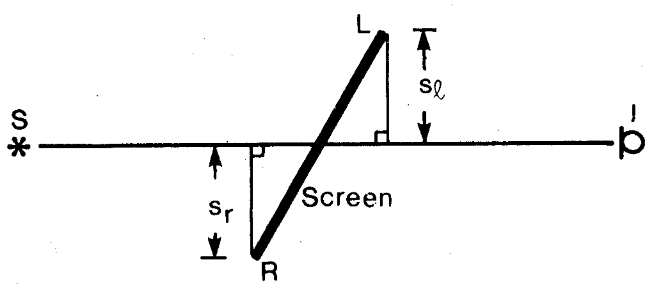

Figure 4.5.2 Plan view of screen.

Note 1: Conditions nos. 1-3 give discontinuity problems if applied rigorously. When the value of ΔL_s is important to the final result of calculations, a judgement should be made in each separate case.

Note 2: The screen mass condition (no. 1) should be frequency dependent. $\Delta L_s = 0$ may be replaced by an estimate if the screen mass is less than specified.

4.5.3 Schematical Screen Representation

Each screening obstacle is in general represented by a thin plane screen with straight edges as shown in Figure 4.5.3. The side edges are vertical, one corner being denoted L (left, seen from the source) and the other R (right). Note that the top edge LR of the screen is not necessarily horizontal. The height of the schematical screen representation should usually be equal to or less than the height of the real screening obstacle.

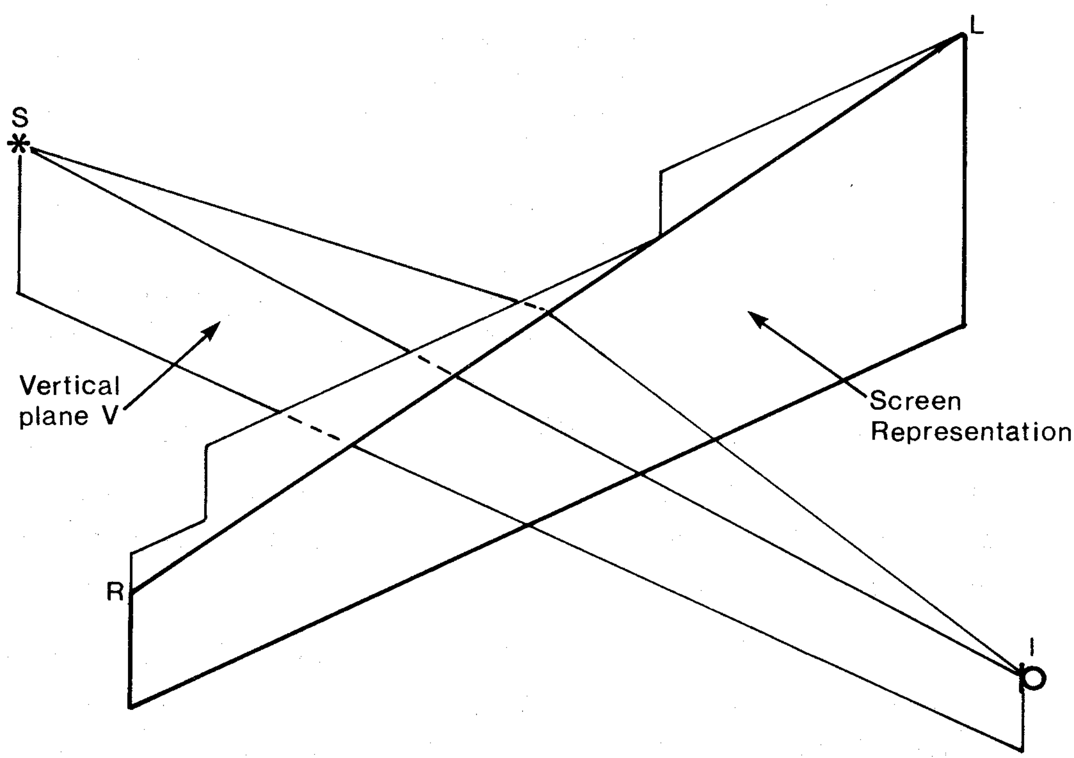

Figure 4.5.3 Illustration of screen representation.

A building is in general represented by one single screen, cf Figure 4.5.4. If the horizontal dimension d_{12} is not very much smaller than the horizontal distance d from the source to the immission point, the building is represented by a box with vertical edges as illustrated in Figure 4.5.4. Each of the building sides is considered a single thin screen. In this case ΔL_s may be calculated according to Appendix C.

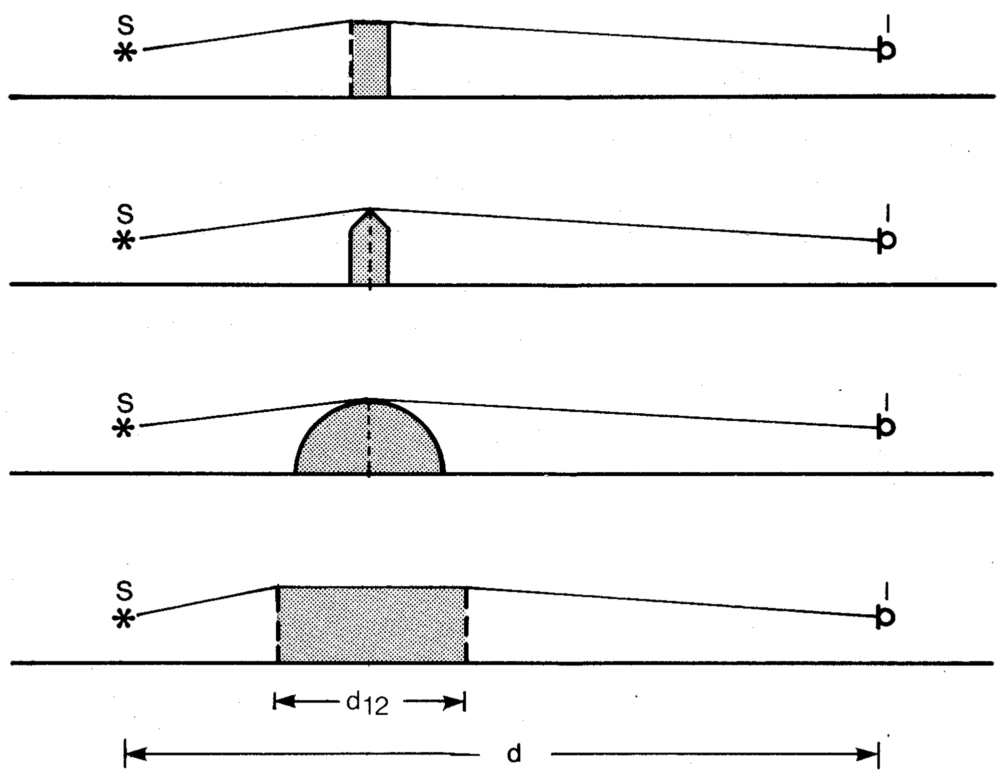

Figure 4.5.4 Examples illustrating a building's screen representation. Sectional view.

4.5.4 ΔL_s When ONE SCREEN Intersects the Plane V

This case represents the basic screening situation to which all other configurations are referred. The procedure is described below in steps 1 to 5:

First the difference δ between transmission path lengths from source to immission point, a) directly and b) via each of the edges of the screen, is calculated (STEPS 1-3). ΔL_s is then calculated (STEPS 4-5). The parameters involved are illustrated in Figure 4.5.5.

STEP 1: Determine the Positions of the Points K, Q, and T

K = The intersection between the line SI from the source S to the immission point I and the screen representation (if necessary extended above the screen top edge LR).

T = The intersection between the screen top edge (LR, Figure 4.5.3) and the vertical plane V (Figure 4.5.3).

Q = The intersection between the screen plane (if necessary extended above LR) and the curved transmission path from S to I as it would have been in the absence of the screen.

Q is always situated above K, the distance from K being:

$$\Delta h = \frac{d_1 \cdot d_2}{16 \cdot d} \quad [m] \qquad (4.5.2)$$

d_1 = horizontal distance from the source to the screen (measured in the plane V), [m]

d_2 = horizontal distance from the immission point to the screen (measured in the plane V), [m]

d = $d_1 + d_2$ [m]

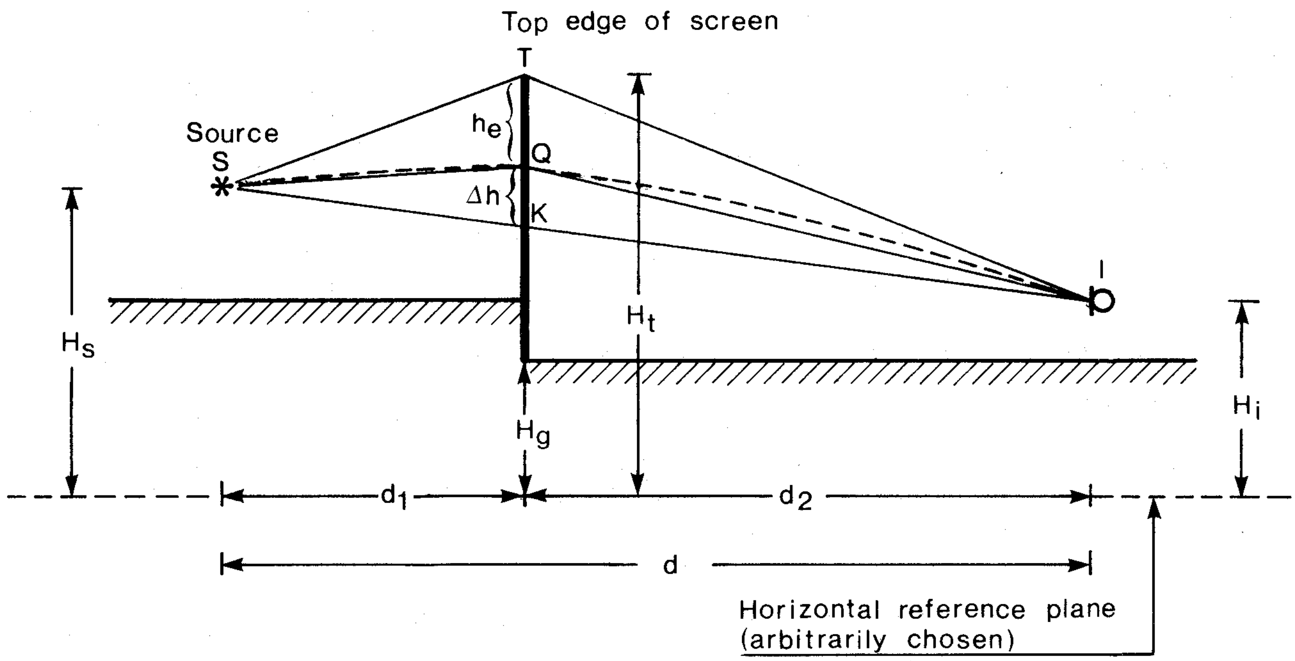

Figure 4.5.5 Geometrical parameters, in the plane V (cf Figure 4.5.6).

The distance from Q to T is the effective height of the screen, h_e. If Q is situated below T, then h_e is positive. If Q is situated above T, then h_e is negative, per definition.

$$h_e = \begin{cases} |KT| - \Delta h & \text{if K is below T} \\ -(|KT| + \Delta h) & \text{if K is above T} \end{cases} \qquad (4.5.3)$$

$|KT|$ indicates the distance between points K and T, cf Figure 4.5.5.

Note: Equation (4.5.2) implies an approximately circular transmission path with a curvature of 8 times the horizontal distance between S and I. This reduces the effect of a screen compared to straight line sound propagation conditions. Limited field data indicate the corrections calculated to correspond to energy mean values within meteorological conditions specified in ref. [4] for immission measurements.

This transmission path curvature is an empirically deduced feature which has not necessarily anything to do with transmission path curvatures occurring e.g. due to vertical gradients in wind speed and temperature. Among other things e.g. the effect of turbulence in air near the edge of screens is included.

STEP 2: Determine the Vertical Transmission Path Difference, δ_v

The vertical transmission path difference δ_v is defined as

$$\delta_v = \begin{cases} |ST|+|TI|-|SQ|-|QI|, \text{ [m], if K is below T} \\ 2 \cdot |SI|-|SQ|-|QI|-|ST|-|TI|, \text{ [m], if K is above T} \end{cases} \quad (4.5.4)$$

$|ST|$ etc. indicates the distance between points S and T, etc., cf Figure 4.5.5.

Note: When a building is represented by a single screen (cf Figure 4.5.4 and 4.5.7), the single screen for which δ_v is greatest is chosen.

STEP 3: Determine the "Horizontal" Transmission Path Differences, δ_r and δ_ℓ

The "horizontal" transmission path differences are calculated as

$$\delta_r = |SK_r|+|K_rI|-|SI|, \text{ [m]}$$
$$\delta_\ell = |SK_\ell|+|K_\ell I|-|SI|, \text{ [m]} \quad (4.5.5)$$

$|SK_r|$ etc. indicates the distance between points S and K_r, etc. The points K_r and K_ℓ are the projections of the point K on the right and on the left vertical edge of the screen, respectively, cf Figure 4.5.6.

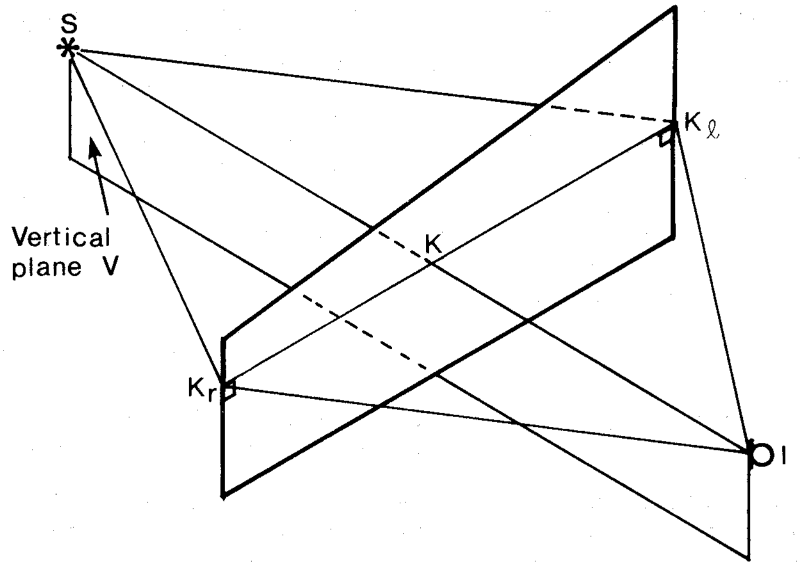

Figure 4.5.6 Illustration of "horizontal" transmission paths.

Note: When a building is represented by a single screen, δ_r and δ_ℓ are calculated for the edges yielding the highest values.

As an example the configuration illustrated in Figure 4.5.7 would yield

$$\delta_r = |SK_{r2}| + |K_{r2}I| - |SI|$$
$$\delta_\ell = |SK_{\ell 1}| + |K_{\ell 1}I| - |SI| \qquad (4.5.6)$$

Indices 1 and 2 refer to screen nos. 1 and 2, indices ℓ and r refer to left and right, seen from the source.

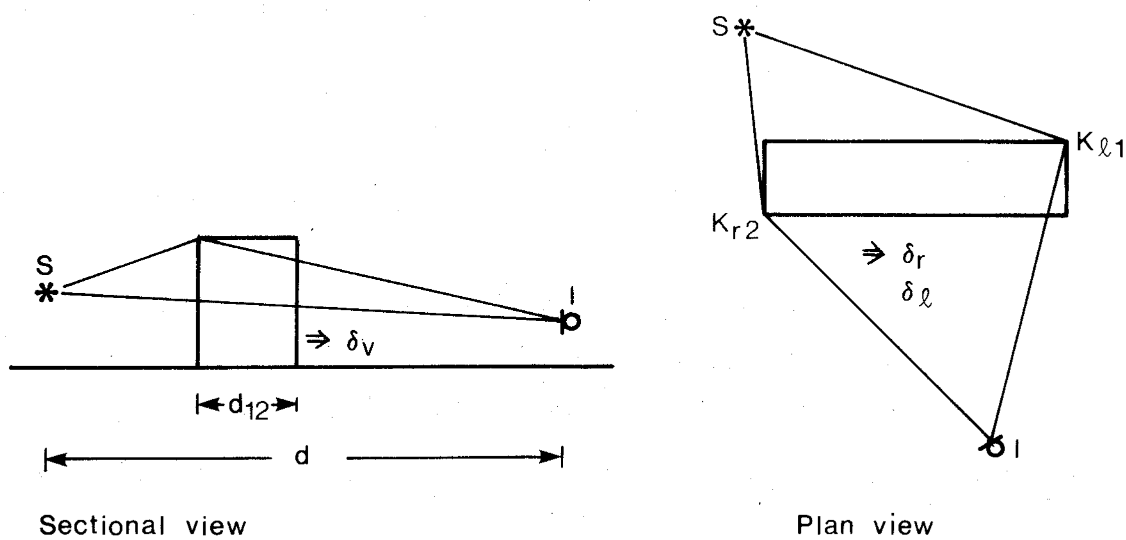

Figure 4.5.7 Example illustrating a building's screen representation, particularly the horizontal transmission path differences.

STEP 4: Determine for Each Transmission Path Difference δ_v, δ_r, and δ_ℓ the Fresnelnumber N

$$N_v = \frac{2 \cdot \delta_v}{\lambda} = 0.0059 \cdot \delta_v \cdot f = \boxed{0.0047 \cdot \delta_v \cdot f_c}$$
$$N_r = 0.0059 \cdot \delta_r \cdot f = \boxed{0.0047 \cdot \delta_r \cdot f_c} \quad (4.5.7)$$
$$N_\ell = 0.0059 \cdot \delta_\ell \cdot f = \boxed{0.0047 \cdot \delta_\ell \cdot f_c}$$

Note: The Fresnelnumber depends on the frequency. Hence a value has to be calculated in each 1/1 octave band.

It is recommended to insert for f the values of the centre frequency for the lowest 1/3 octave band in each 1/1 octave band (with centre frequency f_c). This normally leads to an underestimation of the effect of a screen.

If the recommendation is followed, the value of f to be inserted in equation (4.5.7) is $f_c/\sqrt[3]{2}$. This yields the constant 0.0047. f_c is the 1/1 octave band centre frequency.

STEP 5: Determine the Value of ΔL_s

ΔL_s is calculated using the equation (4.5.8).

$$\left.\begin{array}{l}
\text{If } N_v \leq -0.1:\ \Delta L_s = 0 \\
\text{If } N_v > -0.1:\ \Delta L_s = 10 \cdot C_h \cdot \lg\left\{\left[\dfrac{1}{20N_v+3} + \dfrac{1}{20N_r+3} + \dfrac{1}{20N_\ell+3}\right]\right\} \\
\qquad \text{If } \Delta L_s > 0 \text{ dB, then } \Delta L_s \text{ is set equal to 0 dB} \\
\qquad \text{If } \Delta L_s < -20 \text{ dB, then } \Delta L_s \text{ is set equal to } -20 \text{ dB} \\
\qquad C_h = \dfrac{f_c}{250}(H_t - H_g) \quad [-] \\
\qquad \text{If } C_h \geq 1 \text{, then } C_h \text{ is set equal to 1}
\end{array}\right\} \quad (4.5.8)$$

f_c = octave band centre frequency [Hz]
H_t = height of screen top [m]
H_g = height of lowest ground surface [m]

H_t and H_g are measured above the reference plane, cf Figure 4.5.5.

Note 1: Equation (4.5.8) represents a summation on an energy basis of contributions from vertical and right and left "horizontal" transmission paths. Each of the screen edges (top, right, and left) are in turn assumed to be of infinite length in this connection ($N_r \geq 0$, $N_\ell \geq 0$).

This way of adding contributions is correct only when omnidirectional sources are considered. When pronounced directivity occurs, a better estimate of immission point sound pressure levels will be obtained by separate calculation of each transmission path contribution. An evaluation has to be made in each separate case.

Note 2: If the screen is very long in comparison to its height, i.e. $N_r >> 0$, $N_\ell >> 0$, the equation (4.5.8) becomes the expression valid for an infinitely long screen:

$$\Delta L_s = -10 \cdot C_h \cdot lg(20N_v+3) = -10 \cdot C_h \cdot lg(0.094 \cdot \delta_v \cdot f_c+3) \quad (4.5.9)$$

Note 3: For $N_v \geq 1$, ΔL_s decreases by approximately 3 dB for each doubling of frequency. This facilitates "manual" calculations.

Note 4: The purpose of the correction factor C_h applied in equations (4.5.8) and (4.5.9) is to reduce the effect of a screen in situations where the physical screen height (i.e. $H_t - H_g$) is small in relation to the wavelength. Very limited data are available as to the value of C_h.

4.6 Vegetation, ΔL_v

A curved transmission path is considered. The transmission path height Δh above the straight line between the source and the immission point is given by equation (4.5.2).

If this transmission path passes through dense vegetation of trees and bushes, a correction ΔL_v should be included in the transmission path transfer function.

The vegetation height should exceed the height of the curved transmission path by 1 m or more.
A group of trees and bushes is considered dense if - along the transmission path - it is impossible to see through the vegetation, i.e. if the transmission path is visually blocked.

If the transmission path passes through a number of consecutive groups of trees and bushes, and each of these groups visually blocks the transmission path, the effect of a maximum number of 4 groups is allowed being taken into account. A dense forest is considered a number of groups, each 50 m of transmission path length, d_v, passing through the forest representing one group (cf Figure 4.6.1).

ΔL_v is calculated by equation (4.6.1)

$$\Delta L_v = -n_v \cdot \alpha_v \tag{4.6.1}$$

n_v = number of groups of vegetation

α_v = attenuation coefficient per group, Table 4.6.1

If $n_v > 4$, n_v is set equal to 4.

1/1 octave f_c [Hz]	63	125	250	500	1000	2000	4000	8000
α_v per group [dB/group]	0	0	1	1	1	1	2	3

Table 4.6.1 Values of α_v per group of high and dense vegetation. Maximum 4 groups, minimum 1 m above curved transmission path.

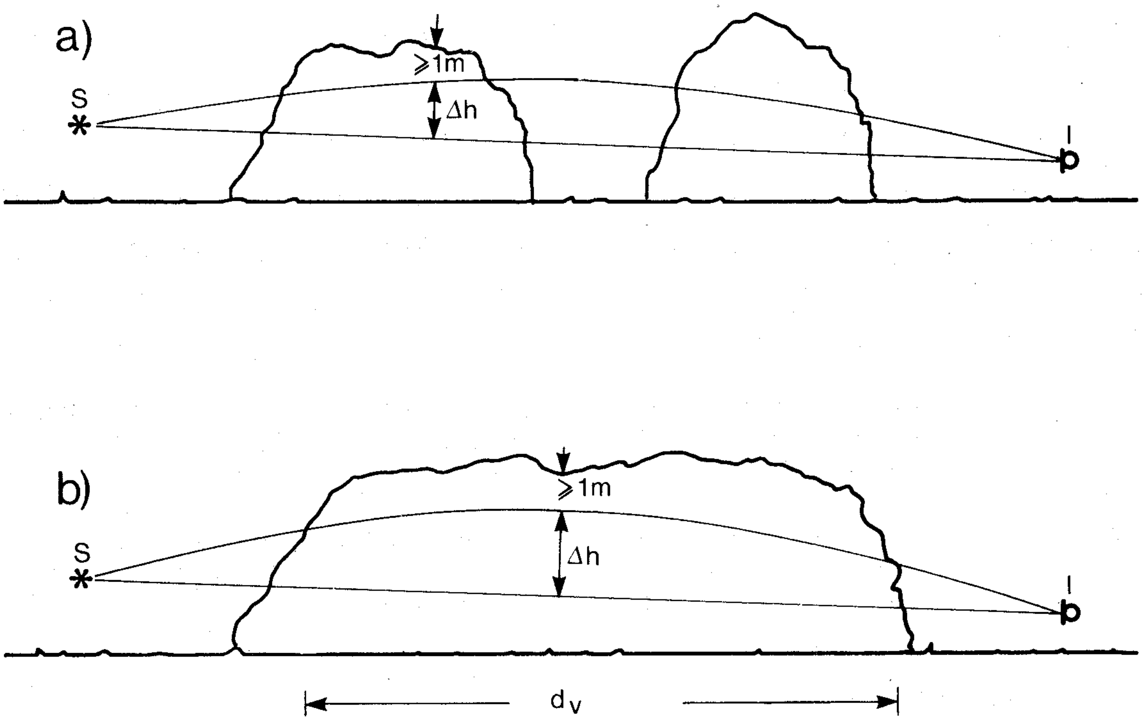

Figure 4.6.1 Illustration of number n of groups of vegetation.

a) $n_v = 2$

b) $n_v = \frac{d_v}{50}$

Note: The values of α_v are valid under both summer and winter conditions provided that the transmission path is visually blocked. Usually this is not the case in wintertime. Under such conditions the values in Table 4.6.1 should be multiplied by 0.5.

4.7 Ground Effect, ΔL_g

4.7.1 Principle

Basically the correction ΔL_g due to the effect of the ground is calculated as the sum of three terms, each of which being related to the properties of different parts of the ground surface between the source and the immission point.

The values of the correction terms depend upon source and immission point height, type of ground surface, distance between source and immission point, and whether or not screening occurs along the transmission path.

Note 1: ΔL_g is intended to predict energy mean values under the meteorological conditions specified for immission measurements, ref. [4].

Note 2: The corrections have been determined by curve fitting to empirical data obtained on level ground. The adaptation to hilly terrain is mentioned in Appendix E.

4.7.2 Parameters

The following parameters are used (cf Figure 4.7.1):

- d is the horizontal distance from the source to the immission point, [m].
- h_s is the source height above the relevant ground surface part (see below), [m].
- h_i is the immission point height above the relevant ground surface part (see below), [m].

The ground surface between the source and the immission point is divided into at least two parts (cf the cross section in Figure 4.7.1) which are defined in Table 4.7.1.

Distinction is made between two types of ground surfaces, i.e. hard and porous. Each of these types have been designated a ground factor G, see Table 4.7.2.

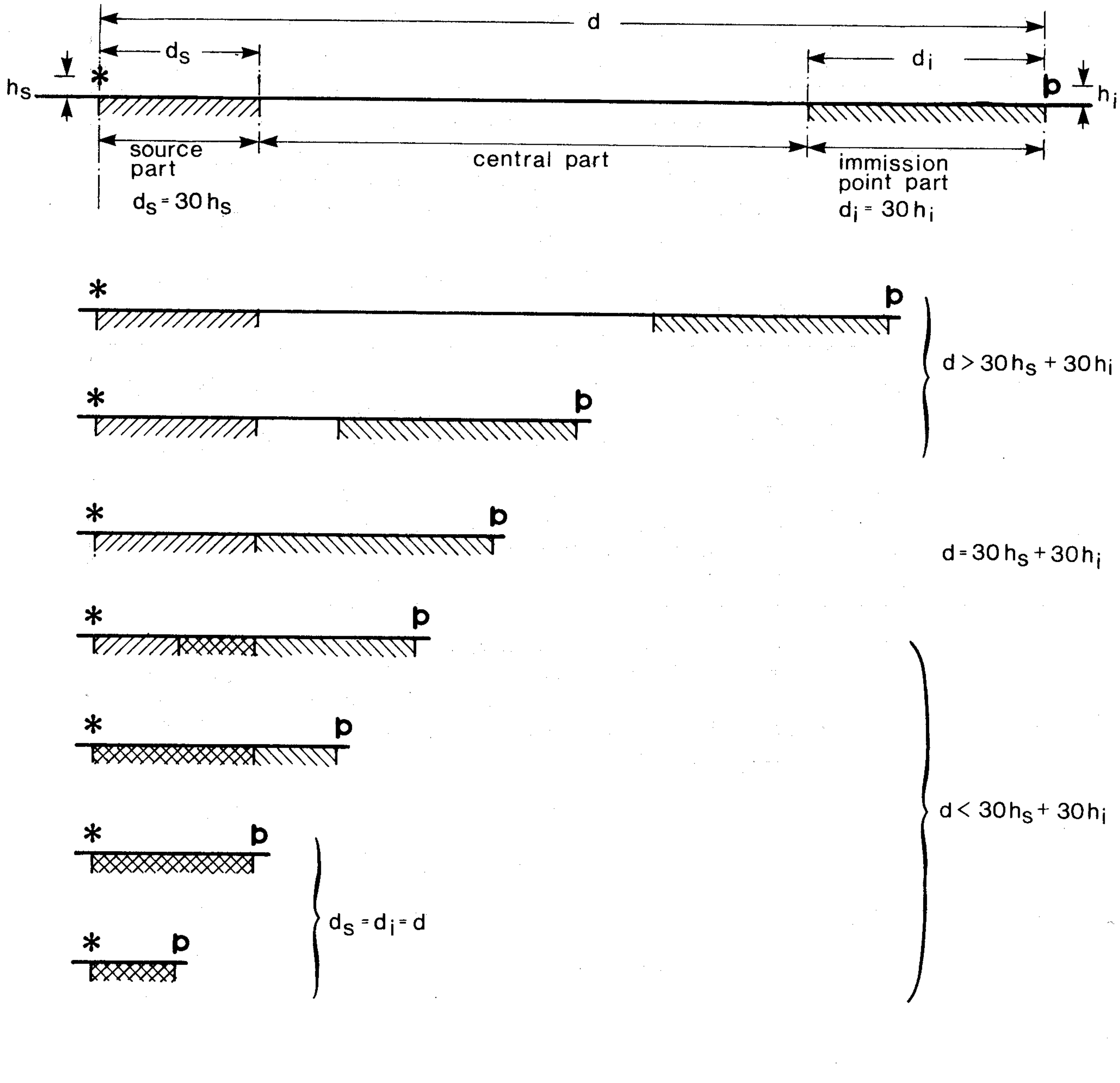

Figure 4.7.1 Sectional view of source and immission point showing three parts of ground surface: source, immission point, and central part, respectively. If $d < 30 \cdot (h_s + h_i)$, there is no central part, and source part and immission point part overlap more or less.

Source part	The source part is the part of the ground surface with the width d_s measured horizontally from the vertical projection of the source on the reference plane. d_s is defined as the minimum value of d and $30 \cdot h_s$.
Immission point part	The immission point part is the part of the ground surface with the width d_i measured horizontally from the vertical projection of the immission point on the reference plane. d_i is defined as the minimum value of d and $30 \cdot h_i$.
Central part	The central part is the part of the ground surface area situated between the source and immission point parts, respectively. If $d < 30 \cdot (h_s + h_i)$, the central part does not exist. In such situations the source part and the immission point part overlap more or less.

Table 4.7.1 Definitions of different ground surface parts. These definitions apply without difficulty in level country. What to do when the ground is not level is mentioned in Appendix E.

Ground surface type/ground factor	Characterization
Hard ground G = 0	Asphalt, pavement, concrete, water, and ground surfaces with many scattering obstacles are considered acoustically hard. Many industrial areas can be regarded as having a hard ground surface. This also includes roofs of industrial buildings. This type of ground surface is designated a ground factor G = 0.
Porous ground G = 1	All surfaces on which vegetation could occur and on which only a few scattering obstacles exist are regarded acoustically porous, e.g. grassland, agricultural ground with and without vegetation, woods, moors, and gardens can be regarded as having an acoustically porous surface. This type of ground surface is designated a ground factor G = 1.
Partly porous ground G = p/100	If a percentage p of the ground surface is porous and the rest is hard, the ground factor G is found by interpolation, i.e. G = p/100 = fraction of porous ground.

Table 4.7.2 Ground surface type characterization and values of ground factors G.

4.7.3 Calculation Procedure

The ground correction ΔL_g in this prediction procedure consists of three contributions each of which can be attributed to one surface part, indicated by indices s (source part), i (immission point part), and c (central part). ΔL_g is calcualted using equation (4.7.1).

$$\Delta L_g = \Delta L_{g,s} + \Delta L_{g,i} + \Delta L_{g,c} \quad [\text{dB}] \tag{4.7.1}$$

The values of each of the contributions can be calculated, in 1/1 octave bands, by means of the expressions summarized in Table 4.7.3.

$\Delta L_g < 0$ indicates attenuation

$\Delta L_g > 0$ indicates amplification

<table>
<tr><th>1/1 octave
f_c
[Hz]</th><th>$\Delta L_{g,s}$ or $\Delta L_{g,i}$
[dB]</th><th>$\Delta L_{g,c}$
[dB]</th></tr>
<tr><td>63</td><td>1.5</td><td>$3\,m$ [5]</td></tr>
<tr><td>125</td><td>$1.5 - G \cdot a(h)$ [1]</td><td rowspan="7">$3\,m(1 - G_c)$ [5]</td></tr>
<tr><td>250</td><td>$1.5 - G \cdot b(h)$ [2]</td></tr>
<tr><td>500</td><td>$1.5 - G \cdot c(h)$ [3]</td></tr>
<tr><td>1000</td><td>$1.5 - G \cdot d(h)$ [4]</td></tr>
<tr><td>2000</td><td>$1.5\,(1 - G)$</td></tr>
<tr><td>4000</td><td>$1.5\,(1 - G)$</td></tr>
<tr><td>8000</td><td>$1.5\,(1 - G)$</td></tr>
</table>

1) $a(h) = 1.5 + 3.0 \cdot e^{-0.12(h-5)^2}(1 - e^{-\frac{d}{50}}) + 5.7 \cdot e^{-0.09h^2}(1 - e^{-2.8 \cdot 10^{-6} \cdot d^2})$

2) $b(h) = 1.5 + 8.6 \cdot e^{-0.09 \cdot h^2}\,(1 - e^{-\frac{d}{50}})$

3) $c(h) = 1.5 + 14.0 \cdot e^{-0.46 \cdot h^2}\,(1 - e^{-\frac{d}{50}})$

4) $d(h) = 1.5 + 5.0 \cdot e^{-0.9 \cdot h^2}\,(1 - e^{-\frac{d}{50}})$

5) $m = 0$ when $d \leq 30\,(h_i + h_s)$

$m = 1 - \frac{30\,(h_s + h_i)}{d}$ when $d > 30\,(h_s + h_i)$

If $m < 0$, m is set equal to zero (cf Note 2, p. 48).

Table 4.7.3 Expressions to be used calculating ground correction contributions $\Delta L_{g,s}$, $\Delta L_{g,i}$, and $\Delta L_{g,c}$, in 1/1 octave bands.

$\Delta L_{g,s}$: To calculate the ground correction contribution $\Delta L_{g,s}$ from the source part, substitute G and h in the expressions in Table 4.7.3 by

$$G = G_s \quad \text{and} \quad h = \begin{cases} h_s & \text{or} \\ h_s + h_{e1}(1 - \frac{d_{s1}}{d}) \end{cases} \qquad (4.7.2)$$

The corrected source height, $h_s + h_{e1}(1 - \frac{d_{s1}}{d})$, is used for calculating $\Delta L_{g,s}$ when $h_s < 5$ m and significant screening occurs, i.e. when the effective height of the screen is positive.

d is the horizontal distance from the source to the immission point.

d_{s1} is the horizontal distance from the source to the nearest screen (no. 1) included in the calculation of δ_v.

h_{e1} is the effective height of screen no. 1.

Note 1: The corrected source height is introduced to account for the reduced effect of the ground, due to the change in transmission path caused by the presence of a screen. The correction is based on a very limited amount of data. The effect ΔL_s of the screen itself is included as described in section 4.5.

Note 2: The extension d_s of the source part of the ground surface is always calculated on the basis of the "physical" source height, h_s.

$\Delta L_{g,i}$: The calculation of the ground correction contribution $\Delta L_{g,i}$ from the immission point part is completely analogous to the calculation of $\Delta L_{g,s}$. G and h in the expressions in Table 4.7.3 are substituted by

$$G = G_i \quad \text{and} \quad h = \begin{cases} h_i & \text{or} \\ h_i + h_{e2}(1 - \frac{d_{i2}}{d}) \end{cases} \qquad (4.7.3)$$

d_{i2} is the horizontal distance from the immission point to the nearest screen (no. 2) included in the calculation of δ_v.

h_{e2} is the effective height of screen no. 2.

$\Delta L_{g,c}$: The ground correction contribution $\Delta L_{g,c}$ from the central part is calculated as indicated in Table 4.7.3.

If h_s and/or h_i is less than 5 m and if significant screening occurs (i.e. $h_e > 0$), the corrected height(s) from equations (4.7.2-3) is(are) used in the expression [5] for *m* in Table 4.7.3.

Note 1: If $d \leq 30\ (h_s + h_i)$, the central part does not exist, and hence $\Delta L_{g,c} = 0$.

Note 2: If the introduction of corrected source/immission point heights leads to $m < 0$, m is set equal to zero.

5. LIST OF SYMBOLS*

A	Index indicating A-weighting (Figure 2.5).
C	Centre of cylinder (Figure in Table 4.4.2).
C_h	Correction factor related to height of screen (equation 4.5.8).
G G_c G_i G_s	Ground factors G for central, immission point, and source parts of ground surface, respectively. G = fraction of porous surface (Table 4.7.2).
H [m]	Height above horizontal reference plane of: H_g: Lowest ground surface adjacent to screen (Figure 4.5.5) H_i: Immission point (Figure 4.5.5) H_s: Source (Figure 4.5.5) H_t: Point T on top edge of screen (Figure 4.5.5) H_o: Reflecting obstacle (equations 4.4.6-7)
I	Immission point.
K	Intersection between screen and straight line SI (Figure 4.5.5).
K_ℓ K_r	Projection of K on left and right edge of screen (Figure 4.5.6).
L	Left (seen from S) top corner of screen (Figure 4.5.3).
L_{Aeq} [dB re 20 μPa]	Equivalent continuous A-weighted sound pressure level (Figure 2.5).
L_p [dB re 20 μPa]	Immission point sound pressure level, per 1/1 octave band (Figure 2.5).
L_{pA} [dB re 20 μPa]	A-weighted sound pressure level (Figure 2.5).
L_W [dB re 1 pW]	Sound power level, per 1/1 octave band (equation 3.1.1).

* Symbols which are exclusively used in Appendices A-F are listed in a supplementary list in Appendix G.

$L_W(\Phi)$ [dB re 1 pW]	(Immission relevant) sound power level in direction Φ (equation 3.1.1).
$L_W(\Phi)_m$ [dB re 1 pW]	Sound power level of mirror source (section 4.4.2).
N [-]	Fresnelnumber (equation 4.5.7), as a function of the frequency.
N_ℓ N_r N_v [-]	N corresponding to transmission path differences δ_ℓ, δ_r, δ_v, respectively (equations 4.5.7 and 4.5.8).
Q	Point on screen, Δh above K (Figure 4.5.5).
R	Distance from source to immission point (Figure 4.2.1). Upper right corner (seen from S) of screen (Figure 4.5.3).
S	Equivalent monopole source position.
S_m	Mirror source position (Figure 4.4.1).
T	Point on top edge of screen in plane V (Figure 4.5.5).
V	Vertical plane through S and I (Figure 4.5.3).
W	Index indicating power.
a(h) [dB] b(h) [dB]	Functions of h (and d) determining value of ΔL_g at f_c = 125 Hz and 250 Hz, respectively (Table 4.7.3).
c	Index indicating centre of 1/1 octave band. Index indicating central ground surface part.
c(h) [dB]	Function of h (and d) determining ΔL_g at 500 Hz (Table 4.7.3).
d [m]	Horizontal distance between S and I.
d(h) [dB]	Function of h (and d) determining ΔL_g at 1000 Hz (Table 4.7.3).
d_1 [m]	Horizontal distance between S and screen.
d_2 [m]	Horizontal distance between I and screen.

d_{12} [m]	Horizontal distance in the plane V between screens nos. 1 and 2 (Figure 4.5.4 and 4.5.7).
d_i [m], d_s [m]	Width of immission point part respectively source part of ground surface (Figure 4.7.1).
d_{i2} [m]	Horizontal distance from immission point to nearest screen (equation 4.7.3) in the plane V.
d_{io} [m]	Horizontal distance from immission point to reflecting obstacle (Figure 4.4.2).
d_{ic} [m]	Horizontal distance from immission point to centre of cylinder (Table 4.4.2).
d_{s1} [m]	Horizontal distance from source to nearest screen (equation 4.7.2) in the plane V.
d_{sc} [m]	Horizontal distance from source to centre of cylinder (Table 4.4.2).
d_{so} [m]	Horizontal distance from source to reflecting obstacle (Figure 4.4.2).
d_v [m]	Transmission path length through vegetation (Figure 4.6.1).
f [Hz]	Frequency, f_c = 1/1 octave band centre frequency.
h_e [m]	Effective height of screen (Figure 4.5.5).
h_i [m], h_s [m]	Height of immission point and source, respectively, above ground (Figure 4.7.1).
h_w [m]	Height of sound radiating wall (Figure 3.2.2).
i	Index indicating - immission point - 1/1 octave band no.
j	Index indicating source no.
ℓ	Index indicating left, seen from source.
ℓ [m]	Greatest dimension of extended source (section 3.2).
ℓ_o [m]	Horizontal dimension of reflecting obstacle (section 4.4).
m [dB]	Function of $(h_i + h_s)$ and d determining $\Delta L_{g,c}$ (Table 4.7.3).

m	Number of transmission paths. Index indicating "mirror".
n [-]	Total number of sources. Number of reflecting surfaces (equation 3.1.2).
n_v [-]	Number of groups of vegetation (equation 4.6.1).
p [%]	Percentage of ground surface area being porous.
r	Index indicating right, seen from source.
s	Index indicating source or screen.
s_ℓ [m] s_r [m]	Projection of line KK_ℓ and KK_r, respectively (Figure 4.5.2 and 4.5.6).
t	Index indicating transmission path no. Index indicating top of screen.
Δh [m]	Height of point Q above point K, i.e. height of curved transmission path above line of sight (Figure 4.5.5).
ΔL [dB]	Corrections taking into account effects marked with indices, cf Table 4.1.1.
Φ Φ' [°]	Directions (Figures 2.2 and 4.4.2).
θ [°]	Angle between direction of incident sound and normal to reflecting surface (Figure 4.4.2).
α_a [dB/m]	Coefficient describing effect of sound absorption in air (section 4.3).
α_v [dB/group]	Coefficient describing effect of group of vegetation (section 4.6).
δ [m]	Transmission path differences Index ℓ: left, horizontal; r: right, horizontal; v: vertical — equations (4.5.4-5)
λ [m]	Wavelength of sound in air. λ_c: at frequency f_c.
ρ [-]	Energy reflection coefficient (section 4.4).
ψ [°]	Supplement to angle between lines SC and IC (Table 4.4.2).

6. REFERENCES

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C O N T E N T S

APPENDICES A - G

APPENDIX A

A. IEC CURVE A CORRECTIONS

To convert linear 1/1 octave band sound pressure levels or sound power levels to A-corrected levels, the corrections from Table A shall be added.

Octave band no. i	1	2	3	4	5	6	7	8
Centre frequency f_c [Hz]	63	125	250	500	1 k	2 k	4 k	8 k
A-correction ΔL_{Ai} [dB]	-26	-16	-9	-3	0	+1	+1	-1

Table A IEC curve A corrections.

APPENDIX B

B. AIR ABSORPTION

The air absorption correction ΔL_a is

$$\Delta L_a = -\alpha_a \cdot R \qquad (4.3.1)$$

α_a is a continuous function of the humidity, the static pressure, and the temperature of the air.

For most industrial noise source spectra α_a may be calculated as the pure tone attenuation coefficient corresponding to the centre frequency at the lowest 1/3 octave band for each octave band. For irregular source spectra ($|slope| > 12$ dB/oct. or containing strong narrow band or pure tone components), or when extra precision is needed (e.g. great distance or for high frequency sources), it may be necessary to calculate α_a at the actual frequency (or frequency band) according to the procedure given in ANSI S 1.26 (ref. [9]) and perform the appropriate integration over the actual frequency band.

Table B below contains values of α_a in dB/m for some temperatures in the range 0-25^{o}C and some relative humidities from 30% to 100% RH. The values for α_a correspond to the pure tone attenuation coefficient for the lowest 1/3 octave band centre frequency.

f_c [Hz] / (f)[Hz] / t, RH	63 (50)	125 (100)	250 (200)	500 (400)	1000 (800)	2000 (1600)	4000 (3150)	8000 (6300)
0°C, 30%	0.000	0.000	0.001	0.002	0.007	0.024	0.059	0.100
50%	0.000	0.000	0.001	0.001	0.004	0.014	0.046	0.121
70%	0.000	0.000	0.001	0.001	0.003	0.010	0.033	0.107
80%	0.000	0.000	0.001	0.001	0.003	0.008	0.029	0.097
100%	0.000	0.000	0.001	0.001	0.002	0.007	0.023	0.080
10°C, 30%	0.000	0.000	0.001	0.002	0.004	0.014	0.047	0.140
50%	0.000	0.000	0.001	0.002	0.003	0.008	0.027	0.097
70%	0.000	0.000	0.001	0.002	0.003	0.007	0.020	0.070
80%	0.000	0.000	0.001	0.002	0.003	0.006	0.018	0.062
100%	0.000	0.000	0.001	0.002	0.003	0.006	0.015	0.050
15°C, 30%	0.000	0.000	0.001	0.002	0.004	0.011	0.037	0.124
50%	0.000	0.000	0.001	0.002	0.004	0.008	0.022	0.077
70%	0.000	0.000	0.001	0.002	0.004	0.007	0.017	0.056
80%	0.000	0.000	0.001	0.002	0.004	0.007	0.016	0.050
100%	0.000	0.000	0.001	0.002	0.004	0.007	0.014	0.042
20°C, 30%	0.000	0.000	0.001	0.002	0.004	0.009	0.029	0.102
50%	0.000	0.000	0.001	0.002	0.004	0.008	0.019	0.063
70%	0.000	0.000	0.001	0.002	0.005	0.008	0.016	0.048
80%	0.000	0.000	0.001	0.002	0.005	0.008	0.016	0.043
100%	0.000	0.000	0.001	0.002	0.005	0.008	0.015	0.038
25°C, 30%	0.000	0.000	0.001	0.003	0.005	0.009	0.024	0.083
50%	0.000	0.000	0.001	0.002	0.005	0.009	0.018	0.053
70%	0.000	0.000	0.001	0.002	0.005	0.010	0.017	0.043
80%	0.000	0.000	0.001	0.002	0.005	0.010	0.017	0.040
100%	0.000	0.000	0.000	0.002	0.005	0.010	0.018	0.038

Table B Attenuation coefficients for air absorption (for pure tones at frequency f) to be used in octave bands centered at f_c.

APPENDIX C

C. SCREENING BY MORE THAN ONE SCREEN

C.1 General

In situations when more than one screen intersect the vertical plane V (cf Figures 4.5.4 and C.2) a selection procedure as described in section C.2 is used to find the two most effective single screens. The screening correction ΔL_s is then calculated according to section C.3 for the selected pair of screens.

Note 1: It must be emphasized that the recommended procedure is of a rather speculative nature and that very few data are available to verify the validity of the results of calculations.

Note 2: A special case, that of a wide building, is illustrated in Figure C.1, cf also Figure 4.5.4. In this special case no selection procedure is needed. ΔL_s is calculated according to section C.3.

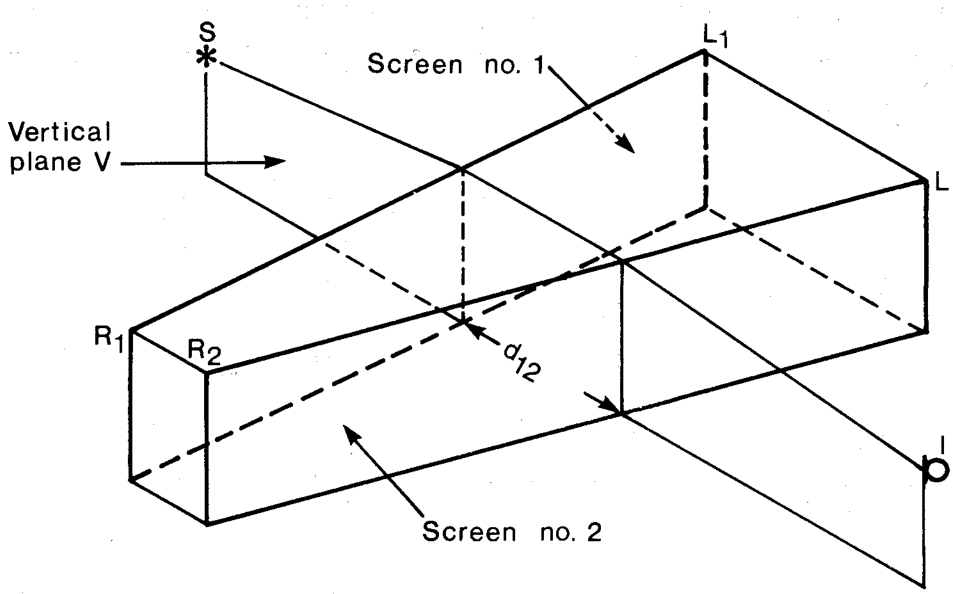


Figure C.1 Representation of a wide building.

C.2 Selection

The selection is based on the effective height h_e of each individual single screen. h_e is determined according to section 4.5.5, STEP 1.

CASE A: No Screens or exactly One Screen for Which $h_e \geq 0$

If no screens or exactly one screen exist for which $h_e \geq 0$, only the screen with the greatest vertical transmission path difference δ_v is considered.

ΔL_s is calculated for this screen as described in section 4.5.5.

Note 1: The effects of all other screens are neglected.

Note 2: If $h_e < 0$ for all screens, only the screen with the smallest numerical value of δ_v is considered ($\delta_v < 0$).

CASE B: More than One Screen for Which $h_e \geq 0$

If more than one screen, intersecting the vertical plane V, have effective heights $h_e \geq 0$, the two most effective of these are selected as described in steps a-d and illustrated in Figures C.2 and C.3.

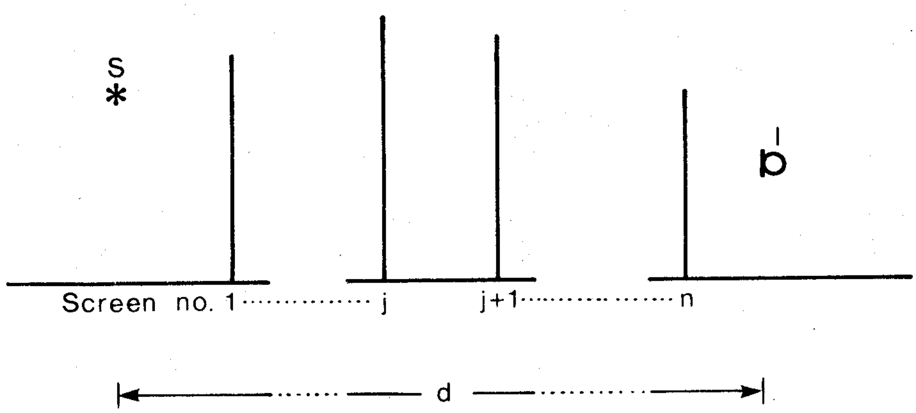


Figure C.2 Sectional view illustrating the general situation when more than one screen intersect the vertical plane.

<u>Step a</u>: "Remove" (i.e. neglect) all screens for which $h_e < 0$.

<u>Step b</u>: Determine for each of the remaining screens (no. j) the position of a point denoted M_j.

M_j is situated at a height $(\Delta h_m)_j$ below the top edge T of the screen

$$(\Delta h_m)_j = \left(h_e \left\{ 1 - \frac{1}{1+h_e/s_r+h_e/s_\ell} \right\} \right)_j \qquad (C.1)$$

h_e is the effective height of the screen.
s_r and s_ℓ are the horizontal dimensions of the screen perpendicular to the line SI (cf Figure 4.5.2).

<u>Step c</u>: "Draw" straight lines connecting the source S and the points M_j (j=1 ... n). Choose the value q of j yielding the highest elevation angle of the line SM_q.

"Draw" straight lines connecting the immission point I and the points M_j (j=1 ... n). Choose the value k of j yielding the highest elevation angle of the line, IM_k.

<u>Step d</u>: If the values of q and k (step c) are equal, ΔL_s is calculated as ΔL_s for a single screen, no. q = k.

If the values of q and k (step c) differ, ΔL_s is calculated as the combined effect of screens nos. q and k. The procedure is described in section C.3.

Note: The procedure in step b is intended to "transform" each screen representation to an equivalent, infinitely long screen. $(\Delta h_m)_j$ is equal to zero for an infinitely long screen. The top edge of the equivalent screen no. j is M_j.

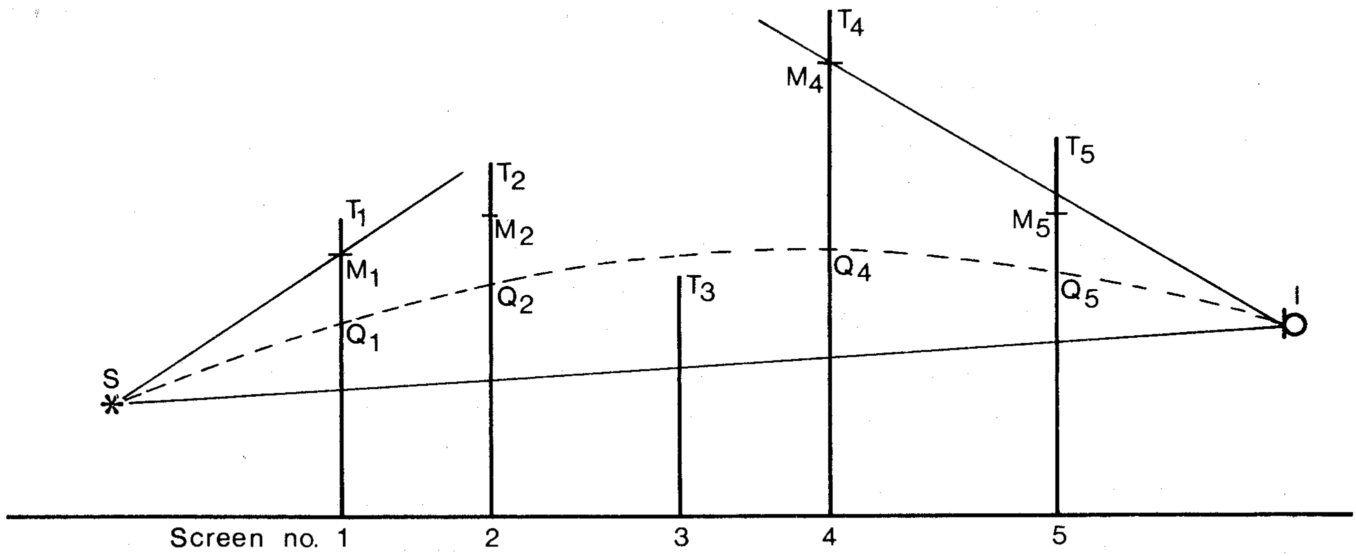


Figure C.3 Sectional view illustrating the selection procedure. $n = 5$. Highest elevation of SM_j is found for $j = q = 1$. Highest elevation of IM_j is found for $j = k = 4$.

C.3 Calculation of ΔL_s

The selection procedure described in section C.2 leaves two screens, nos. q and k. The combined screening correction ΔL_s is calculated according to equation (C.2).

$$\Delta L_s = \Delta L_{sq} + \Delta L_{sk,h} \tag{C.2}$$

ΔL_{sq} is the correction calculated according to section 4.5.5 assuming screen no. q to be the only screen present (cf Figure C.4).

$\Delta L_{sk,h}$ is a correction calculated assuming screen no. k to be the only screen present and the source to be a hypothetical source S_h on top of screen no. q (cf Figure C.4).

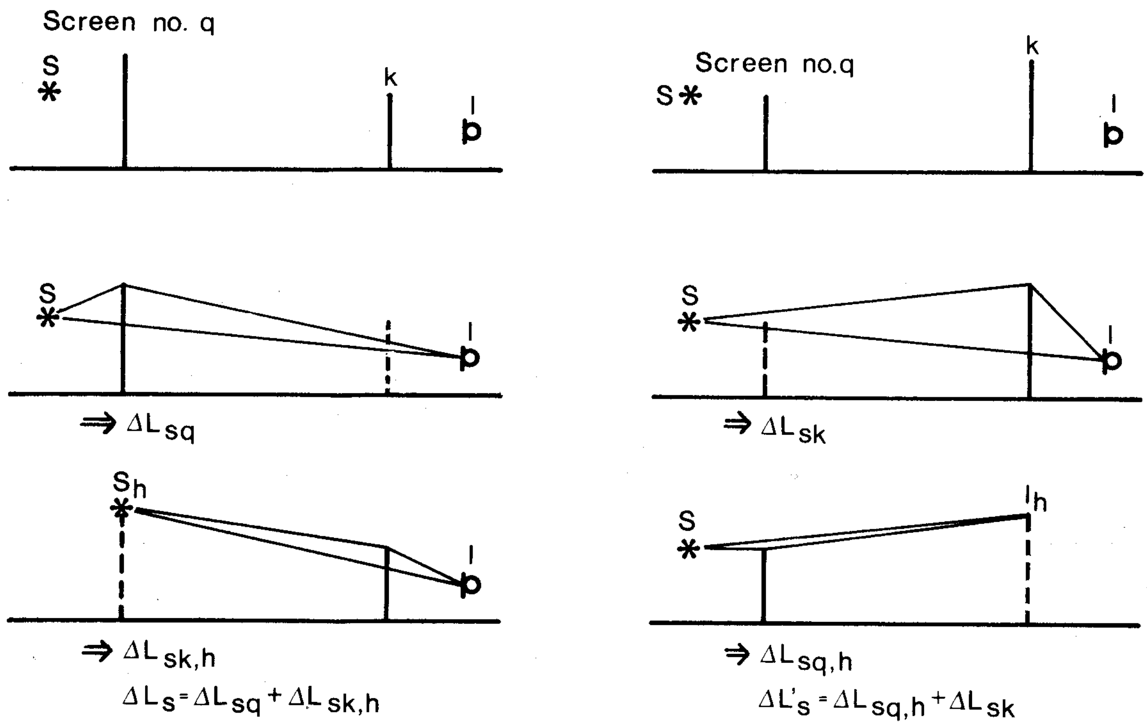


Figure C.4 Sectional view illustrating the calculation of ΔL_s for two screens, nos. q and k.

Note: It is recommended also to calculate the corresponding value

$$\Delta L'_s = \Delta L_{sq,h} + \Delta L_{sk} \qquad (C.3)$$

placing a hypothetical immission point on top of screen no. k, and to choose as the final value of ΔL_s the minimum value according to equations (C.2) and (C.3), respectively.

APPENDIX D

D. INTERNAL SCATTERING, ΔL_i

Very little information is available concerning the effects of sound scattering inside industrial areas.

Therefore, in situations where these effects are considered important, it is recommended to carry out attenuation measurements in appropriate transmission path heights in situ. Parameters influencing sound transmission are type, density, diameter, and height of installations and/or obstacles.

If the correction ΔL_i is taken into consideration in this way, obviously no correction ΔL_s due to screens or ΔL_r due to reflections inside the plant should be included in the transmission path transfer function.

The data stated in Table D give an indication of the order of magnitude of ΔL_i to be expected in open structure process plants. These values may be used for planning purposes. ΔL_i is calculated using the equation (D.1).

$$\Delta L_i = - \alpha_i \cdot \Delta d_i \quad [dB] \tag{D.1}$$

If $\Delta L_i < -10$ dB, ΔL_i is set equal to -10 dB.

α_i is an attenuation coefficient, [dB/m] (Table D).

Δd_i is the length of the part of the transmission path passing through the installation, [m].

1/1 octave f_c [Hz]	63	125	250	500	1000	2000	4000	8000
α_i [dB/m]	0.00	0.02	0.05	0.05	0.05	0.05	0.05	0.05

Table D Approximate values of α_i to be used for open structure process plant planning purposes.

Note: Unpublished Dutch results of measurements indicate that these values are too low.

APPENDIX E

E. GROUND EFFECT WHEN THE GROUND SURFACE IS NOT HORIZONTAL AND LEVEL

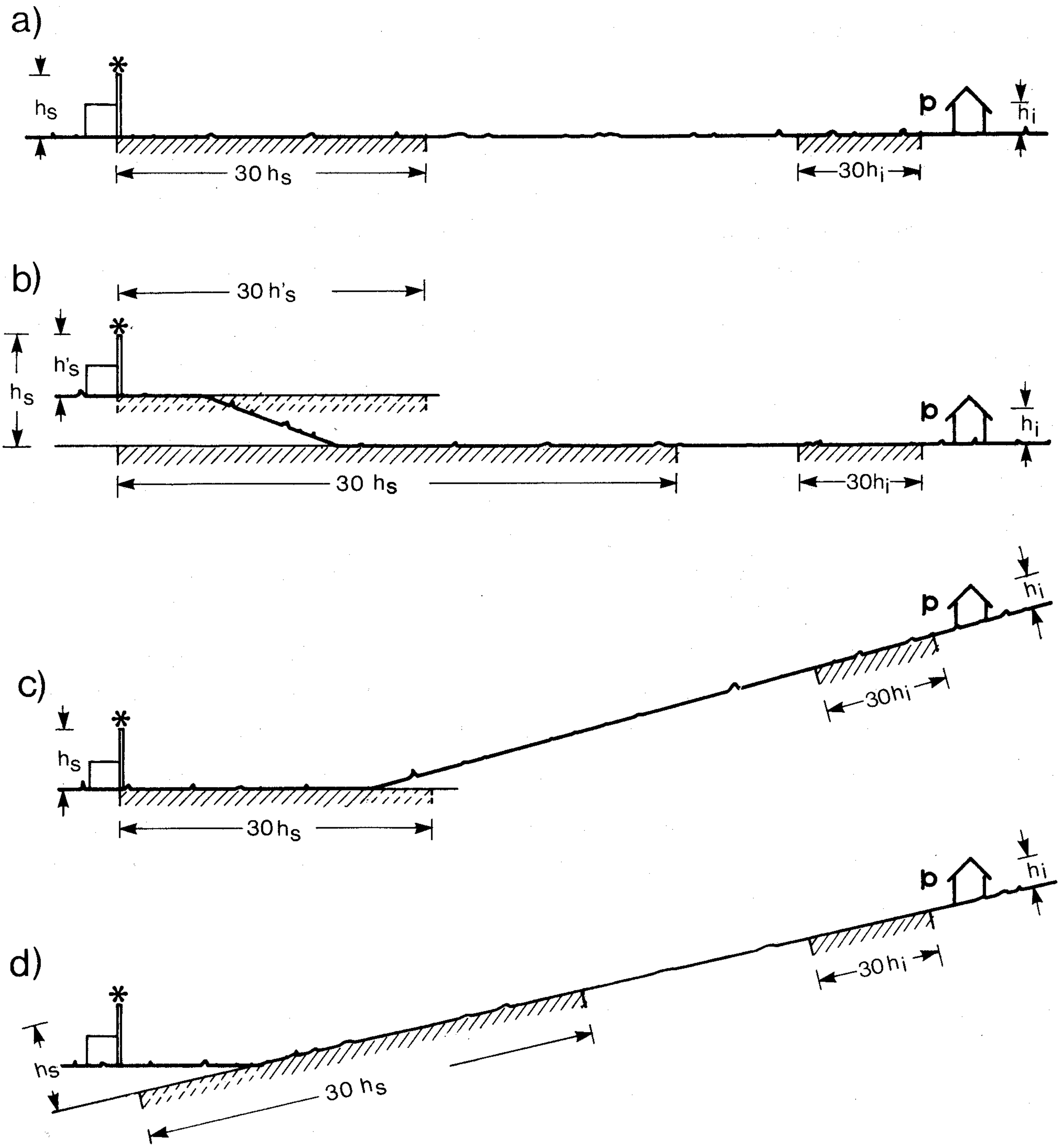
The sound propagation model, upon which the procedures specified in section 4.7 are based, has been developed for level ground. The correction expressions in Table 4.7.3 represent results of curve fitting on field data obtained on level ground.

Recommended procedures for the definition of source and immission point heights above ground, h_s and h_i, and source part, respectively immission point part of the ground surface, are shown in Figure E for various types of sections in hilly ground surface. The central part is always the part in between source and immission point parts.

Note: The validity of this extrapolation of the model has not been proved.

In Figure E.b), h'_s is the height above the "local" ground surface. $30 \cdot h'_s$ extends over a portion of the lower ground surface further away. Therefore a new height h_s is defined, and accordingly also a new source part of the ground surface.

In Figure E.f) an extreme situation is illustrated. In such a case it is recommended to neglect the ground effect contribution from the central part.


a)
hs
30 hs
p
hi
30hi
b)
30 h's
h's
hs
30 hs
p
hi
30hi
c)
hs
30hs
p
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d)
hs
30 hs
p
hi
30 hi

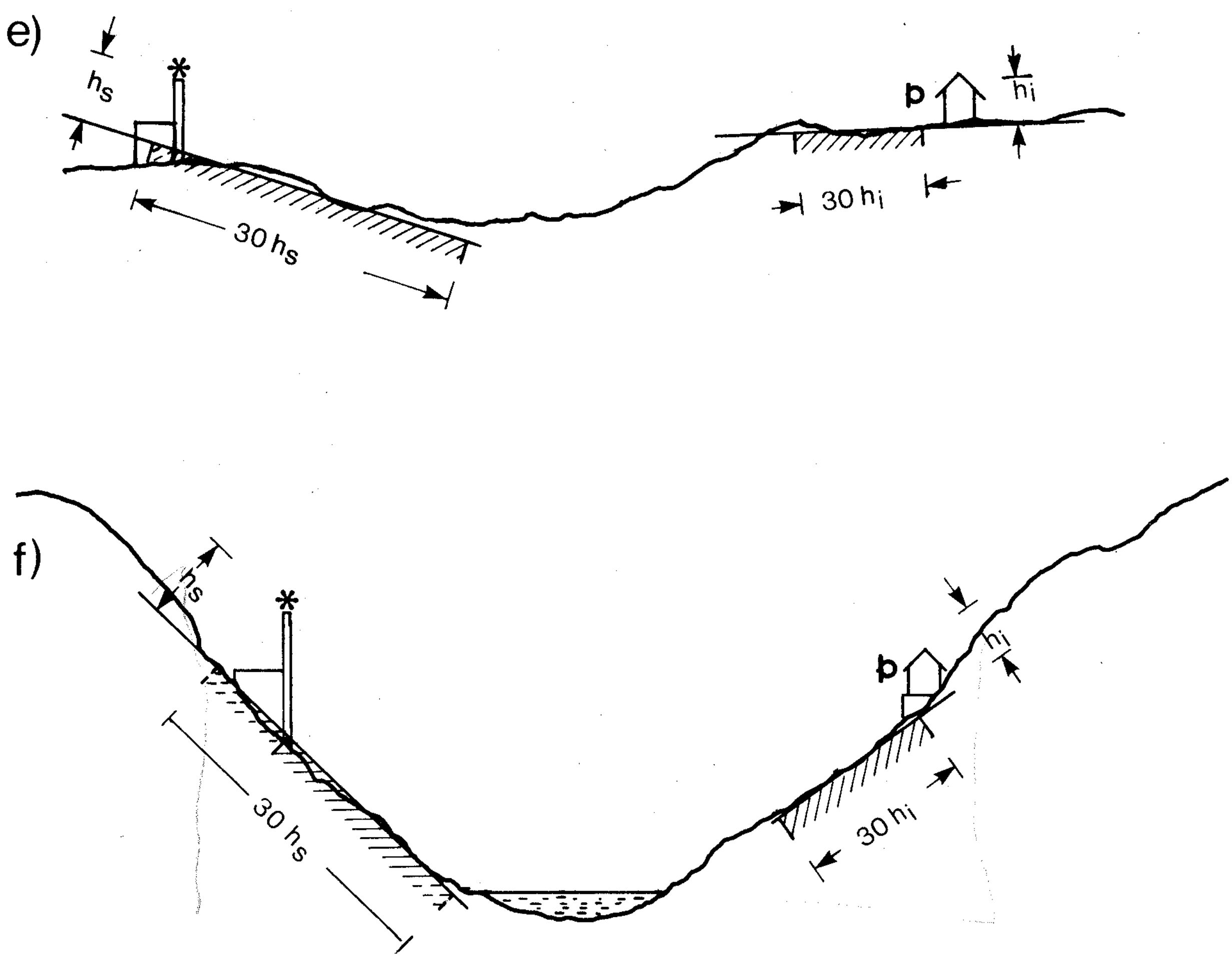


Figure E Sectional views illustrating the definitions of source and emission point heights in hilly terrain.

APPENDIX F

F. EXAMPLES

The examples below are all based on the situation illustrated in Figures F.1 and F.2. The industry considered is a stone crusher installation with overall dimensions 50 × 5 × 7,5 m , site no. 1 in ref. [6]. There is no separate part of the source, which dominates the noise emission. Normally the source operates constantly with a stationary noise emission.

According to ref. [6] horizontal sound power levels are as indicated in Table F.1, and relevant directivity data as indicated in Table F.2.

Octave band f_c [Hz]	63	125	250	500	1000	2000	4000	8000	A-w
L_W [dB re 1 pW]	114	116	118	116	114	113	109	99	119

Table F.1 Sound power levels of stone crusher, ref. [6].

Octave band f_c [Hz]	63	125	250	500	1000	2000	4000	8000	A-w
Direction 45°	-2	-2	-1	-1	-2	-2	-1	-1	-1
Direction 110°	-2	-3	-1	-3	-3	-3	-3	-1	-3

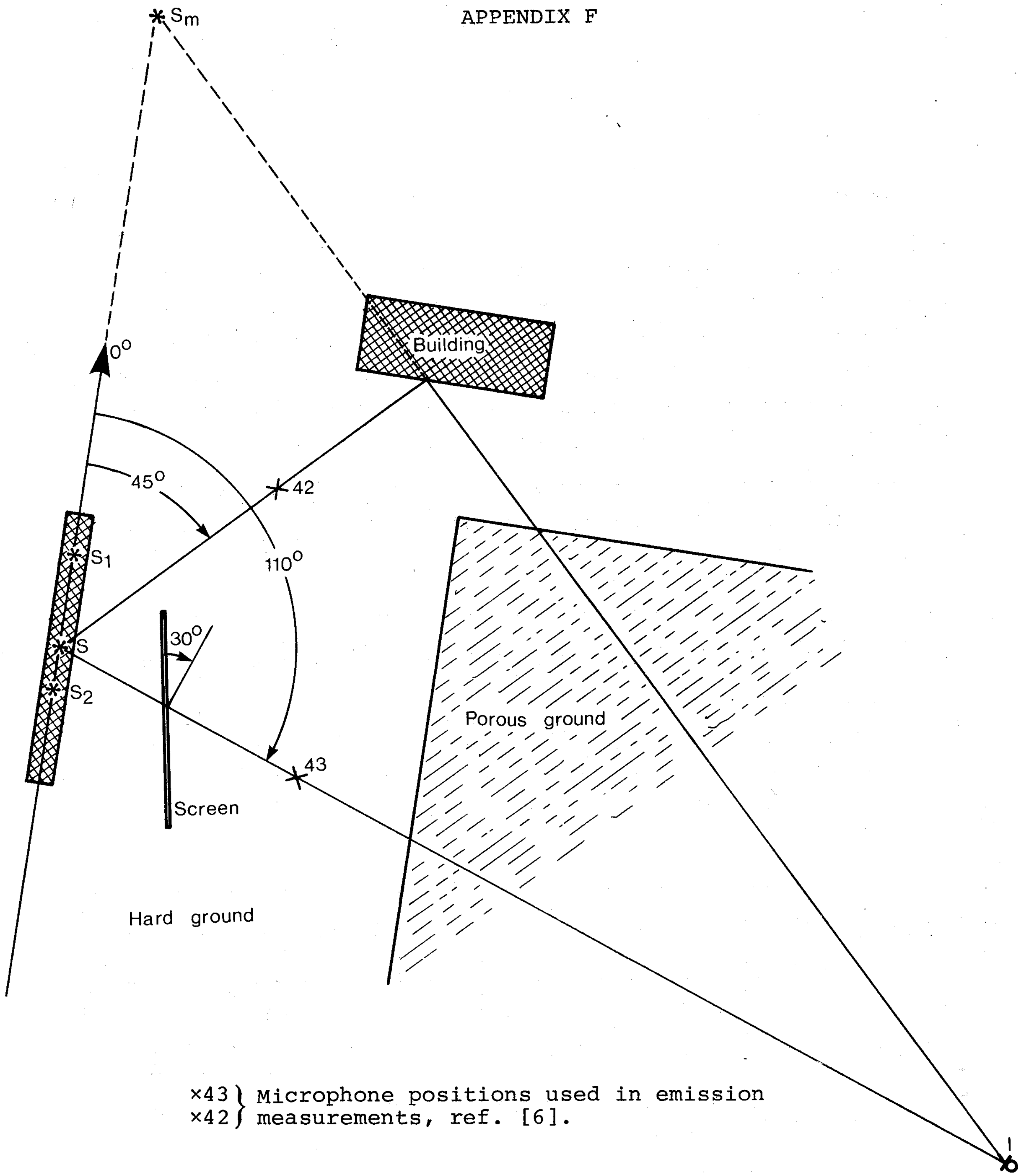
Tabel F.2 Directivity correction ΔL_Φ, ref. [6], cf section 3.1, Note 2.

F.1 Example 1

Determine L_{pA} in the immission point, with no screen or reflecting building present.

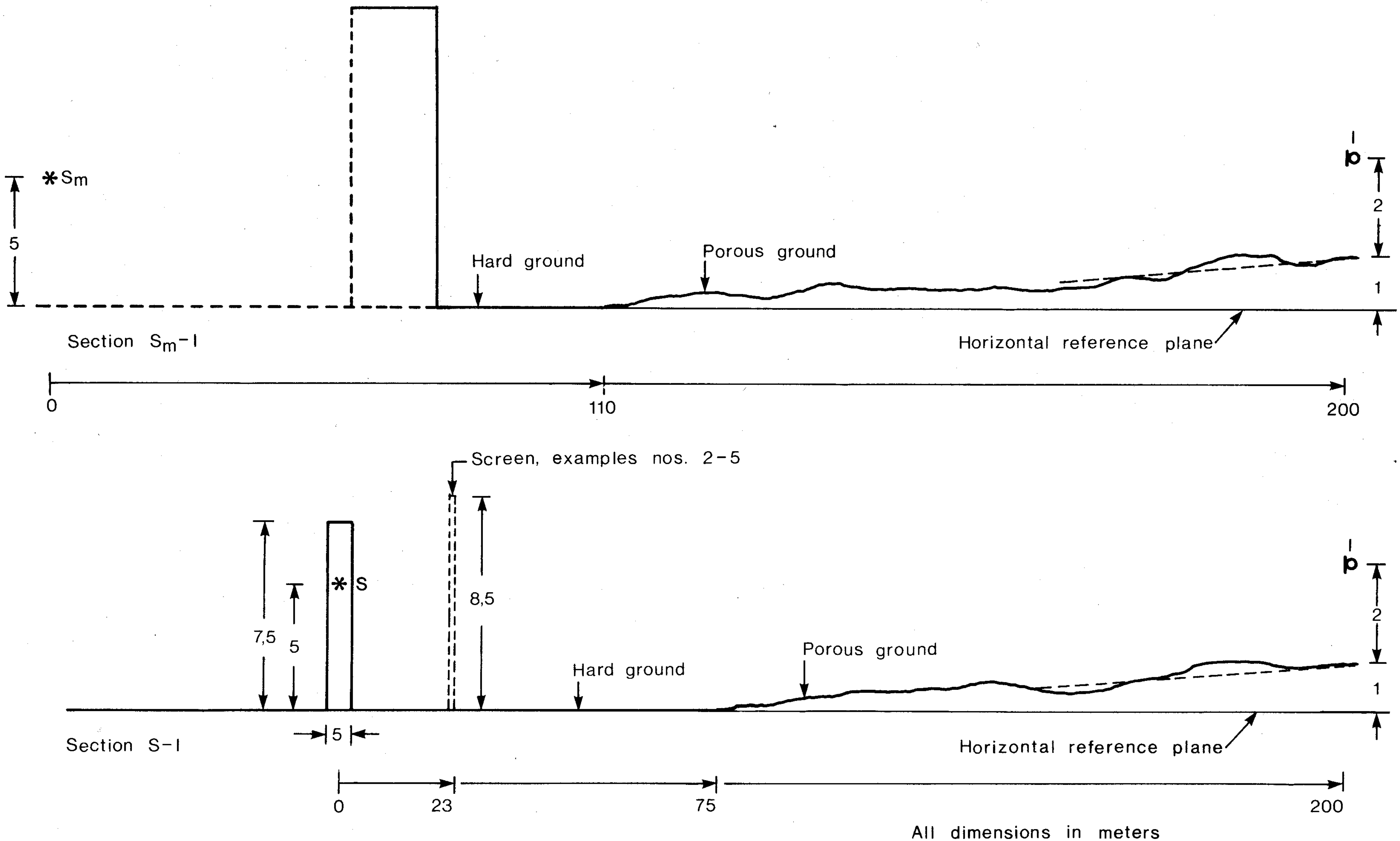
$L_W(\Phi)$: The immission relevant source sound power level is found by means of equation (3.1.1) and data from

APPENDIX F



×43 } Microphone positions used in emission
×42 } measurements, ref. [6].

Figur F.1 Stone crusher and surroundings, schematical according to ref. [6], site no. 1. Plan view 1:1000.



Figur F.2 Cross sections in Figure F.1. Horizontal 1:1000. Vertical 1:200.

Tables F.1-2, applying ΔL_Φ for 110^o. The data are entered in worksheet no. 1.

ΔL_d: The source height $h_s = H_s = 5$ m. The immission point height $h_i = H_i - 1$ m = 2 m. The horizontal distance from S to I is 200 m. ΔL_d is found by means of equation

ΔL_a: (4.2.1) and ΔL_a according to (4.3.1). $\Delta L_r = 0$ since no reflecting buildings are present, and similarly $\Delta L_s = 0$, $\Delta L_v = 0$.

$\Delta L_{g,s}$: $h_s = 5$ m yields $d_s = 150$ m (Table 4.7.1), and p = 50% for the source part of the ground surface. According to Table 4.7.2 G_s is then 0.5. $\Delta L_{g,s}$ is calculated according to Table 4.7.3. In the expressions $a(h)$, $b(h)$, $c(h)$, and $d(h)$ $h = h_s = 5$ m and d = 200 m. The results have been entered in Table F.3 (the decimals in the table are included as test data for the calcualtion of $a(h)$ .... $d(h)$).

$\Delta L_{g,i}$: $h_i = 2$ m yields $d_i = 60$ m (Table 4.7.1), and p = 100% for the immission point part of the ground surface. Hence $G_i = 1$ (Table 4.7.2). Table 4.7.3 with $h = h_i = 2$ m and d = 200 m yields the values of $\Delta L_{g,i}$ entered in Table F.3.

$\Delta L_{g,c}$: Since $d = 200 \text{ m} < 30\cdot(h_s + h_i) = 30\cdot(5 + 2) = 210$ m, the central part does not exist (Figure 4.7.1) and hence $\Delta L_{g,c} = 0$ (Table 4.7.3).

f_c [Hz]	63	125	250	500	1000	2000	4000	8000
$\Delta L_{g,s}$ [dB]	1.5	-0.7544	0.3051	0.7499	0.7500	0.75	0.75	0.75
$\Delta L_{g,i}$ [dB]	1.5	-1.4215	-5.8901	-2.1827	-0.1341	0	0	0
$\Delta L_{g,c}$ [dB]	0	0	0	0	0	0	0	0
ΔL_g [dB]	3	-2.2	-5.6	-1.4	0.6	0.8	0.8	0.8

Table F.3 Ground correction, Example 1.

WORKSHEET NO. 1

Source (no. j): Stone Crusher, S1
Immission point: I
Transmission path: Directly, unscreened.

f_c	Hz	63	125	250	500	1000	2000	4000	8000	Cf section
L_W	dB re 1 pW	114	116	118	116	114	113	109	99	
ΔL_Φ	dB	-2	-3	-1	-3	-3	-3	-3	-1	
$L_W(\Phi)$	dB re 1 pW	112	113	117	113	111	110	106	98	3.1
ΔL_d	dB	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	4.2
ΔL_a	dB	0.0	0.0	-0.2	-0.4	-0.8	-1.4	-3.4	-11.2	4.3
ΔL_r	dB	-	-	-	-	-	-	-	-	4.4
ΔL_s	dB	-	-	-	-	-	-	-	-	4.5
ΔL_v	dB	-	-	-	-	-	-	-	-	4.6
ΔL_g	dB	3.0	-2.2	-5.6	-1.4	0.6	0.8	0.8	0.8	4.7
ΔL_i	dB	-	-	-	-	-	-	-	-	Appendix D
Other ΔL	dB	-	-	-	-	-	-	-	-	
$\Sigma \Delta L$	dB	-54	-59	-63	-59	-57	-58	-60	-67	
L_p	dB re 20 µPa	58	54	54	54	54	52	46	31	
ΔL_A	dB	-26	-16	-9	-3	0	+1	+1	-1	
$L_p + \Delta L_A$	dB re 20 µPa	32	38	45	51	54	53	47	30	L_{pA} = 58 dB re 20 µPa

Φ = 110°

d = 200 m

Example 1

ΔL_g: The values of ΔL_g are calculated in Table F.3 according to equation (4.7.1) and entered in worksheet no. 1.

$\Sigma\Delta L$: The transfer function is calculated in worksheet no. 1 and added to $L_W(\Phi)$, and thus the octave band sound pressure levels L_p at the immission point are determined (equation (2.2)). Finally A-correction is applied, and

L_p:

L_{pA}: L_{pA} is calculated as indicated in equation (2.3).

F.2 Example 2

Determine L_{pA} in the immission point if an 8.5 m high, infinitely long screen is placed as shown in Figures F.1 and F.2, and no reflecting building is present.

$L_W(\Phi)$, ΔL_d, and ΔL_a are as in Example 1, $\Delta L_r = 0$. These are entered in worksheet no. 2.

ΔL_s: To calculate ΔL_s, $\Delta h = \frac{23 \cdot 177}{16 \cdot 200} = 1.27$ m is calculated by means of (4.5.2). The point K (Figure 4.5.5) is 4.77 m above the horizontal reference plane (interpolation between S and I, Figure F.2). Therefore K is below T, which is 8.5 m above the reference plane. The vertical transmission path difference δ_v is then (4.5.4): $\delta_v = |ST| + |TI| - |SQ| - |QI|$ in which by simple geometry: $|ST| = 23.26$ m, $|TI| = 177.09$ m, $|SQ| = 23.02$ m, $|QI| = 177.02$, Q being at the height of $K + \Delta h$, i.e. $4.77 + 1.27 = 6.04$ m above the reference plane. $\delta_v = 0.30$ m.

According to (4.5.9) $\Delta L_s = -10 \cdot C_h \cdot \lg(0.094 \cdot \delta_v \cdot f_c + 3)$. $C_h = \frac{f_c}{250}(H_t - H_g) = \frac{f_c}{250}(8.5 - 0) > 1$ for $f > 30$ Hz. Therefore C_h is set equal to 1 at all frequencies. Thus $\Delta L_s = -10 \lg(0.094 \cdot 0.30\, f_c + 3)$. The values are shown in Table F.4. In the 4000 and 8000 Hz octave bands ΔL_s is set equal to ÷20 dB. ΔL_s is entered in worksheet no. 2.

f_c [Hz]	63	125	250	500	1000	2000	4000	8000
ΔL_s [dB]	-6.79	-8.15	-10.02	-12.33	-14.94	-17.74	-20.64	-23.59

Table F.4 ΔL_s in octave bands, Example 2.

ΔL_g: $\Delta L_{g,s}$: ΔL_g is modified compared to Example 1, due to the introduction of the screen. The source part contribution is the same as in Example 1, however, since h_s = 5 m.

$\Delta L_{g,i}$: The immission point height shall be corrected (4.7.3) since δ_v = 0.30 m > 0 and h_i = 2 m < 5 m. The effective height of the screen $h_e = |QT| = 8.5 - 6.04 = 2.46$ m. The corrected immission point height is (4.7.3) $h = h_i + h_e(1 - \frac{d_2}{d}) = 2 + 2.46(1 - \frac{177}{200}) = 2.28$ m. The corresponding values of $\Delta L_{g,i}$ (Table 4.7.3) are shown in Table F.5.

$\Delta L_{g,c}$: $\Delta L_{g,c}$ is still equal to zero, since $d = 200$ m $< 30(h_s + h_i)$.

f_c [Hz]	63	125	250	500	1000	2000	4000	8000
$\Delta L_{g,s}$ [dB]	1.5	-0.75	0.31	0.75	0.75	0.75	0.75	0.75
$\Delta L_{g,i}$ [dB]	1.5	-1.59	-5.29	-1.23	-0.04	0	0	0
$\Delta L_{g,c}$ [dB]	0	0	0	0	0	0	0	0
ΔL_g [dB]	3.0	-2.3	-5.0	-0.5	0.7	0.8	0.8	0.8

Table F.5 Ground correction, Example 2.

L_{pA} is calculated as in Example 1, cf worksheet no. 2. The effect of the screen is most important to L_{pA} in the 500-2000 Hz octave bands. Overall screen effect is 14 dB L_{pA} reduction.

Note: The change in $\Delta L_{g,i}$ induced by the screen is less than 1 dB (compare Tables F.3 and F.5).

WORKSHEET NO. 2

Source (no. j): Stone Crusher, S^1
Immission point: I
Transmission path: via infinitely long screen

f_c	Hz	63	125	250	500	1000	2000	4000	8000	Cf section
L_W	dB re 1 pW									
ΔL_Φ	dB									
$L_W(\Phi)$	dB re 1 pW	112	113	117	113	111	110	106	98	3.1
ΔL_d	dB	-57.0	-57.0	-57.0	-57.0	-67.0	-57.0	-57.0	-57.0	4.2
ΔL_a	dB	0.0	0.0	-0.2	-0.4	-0.8	-1.4	-3.4	-11.2	4.3
ΔL_r	dB	-	-	-	-	-	-	-	-	4.4
ΔL_s	dB	-6.8	-8.2	-10.0	-12.3	-14.9	-17.7	-20*)	-20*)	4.5
ΔL_v	dB	-	-	-	-	-	-	-	-	4.6
ΔL_g	dB	3.0	-2.3	-6.0	-0.5	0.7	0.8	0.8	0.8	4.7
ΔL_i	dB	-	-	-	-	-	-	-	-	Appendix D
Other ΔL	dB	-	-	-	-	-	-	-	-	
$\Sigma \Delta L$	dB	-61	-68	-72	-70	-72	-75	-80	-87	
L_p	dB re 20 µPa	51	45	45	43	39	35	26	11	
ΔL_A	dB	-26	-16	-9	-3	0	+1	+1	-1	
$L_p + \Delta L_A$	dB re 20 µPa	25	29	36	40	39	36	27	10	L_{pA} = 44 dB re 20 µPa

Φ = 110°, $L_W(\Phi)$ as in worksheet no. 1
d = 200 m
δ_v = 0.30 m
*) limited.

Example 2.

F.3 Example 3

Determine L_{pA} at the immission point if an 8.5 m high, 40 m long screen is introduced as shown in Figure F.1. The stone crusher is represented by one monopole source only. There is still no reflecting building present.

The only change in this example compared to Example 2 occurs in the value of ΔL_s. To apply (4.5.8) the horizontal transmission path lengths must be calculated. In Figure F.3 the horizontal dimensions of the screen are shown. Simple triangle

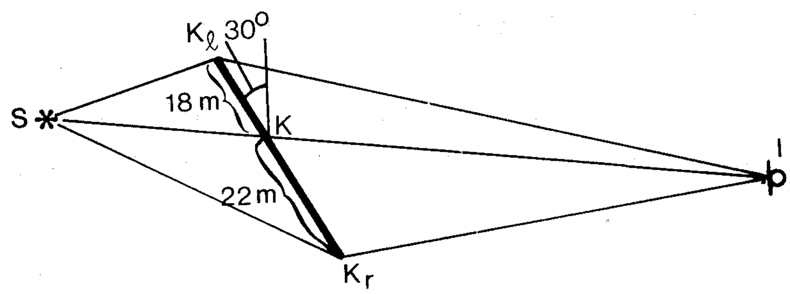


Figure F.3 Illustration of horizontal transmission paths.

calculations yields $|SK| = 23.00$ m, $|KI| = 177.01$ m, $|SK_r| = 38.98$ m, $|K_rI| = 167.10$ m, $|SK_\ell| = 20.95$ m, $|K_\ell I| = 186.66$ m, $|SI| = 200.01$ m, and hence $\delta_\ell = |SK_\ell|+|K_\ell I|-|SI| = 7.60$ m, $\delta_r = |SK_r|+|K_rI|-|SI| = 6.07$ m.

The corresponding Fresnelnumbers (4.5.7) and ΔL_s values (4.5.8) have been summarized in Table F.6.

Note: The change in ΔL_S compared to Table F.4, due to the limited length of the screen, is less than 1 dB in all octave bands. This is a consequence of the rather effective horizontal screening of the one monopole representing the noise source.

f_c [Hz]	63	125	250	500	1000	2000	4000	8000
N_ℓ (δ_ℓ = 7.60 m)	2.25	4.47	8.93	17.86	35.72	71.4	143	286
N_r (δ_r = 6.07 m)	1.80	3.57	7.13	14.26	28.53	57.1	114	228
N_v (δ_v = 0.30 m)	0.09	0.18	0.35	0.71	1.41	2.82	5.64	11.3
$\sum_{\ell,r,v} \frac{1}{20N+3}$	0.26	0.18	0.11	0.06	0.03	0.02	0.01	0.005
ΔL_s [dB]	-5.9	-7.5	-9.5	-11.9	-14.5	-17.4	-20.6	-23.2

Tabel F.6 Fresnelnumbers and ΔL_s, Example 3.

The final result of the calculations made in worksheet no. 3 is a less than 1 dB change in L_{pA} relative to Example no. 2.

F.4 Example 4

Determine L_{pA} at the immission point, provided the situation is as in Example 3, but the source is subdivided into a screened and an unscreened part.

The 50 m long stone crusher is divided into a 7 m long unscreened part represented by the monopole S_1 in Figure F.1, and a 43 m long screened part represented by S_2. The contributions from each of these have to be added to calculate the noise immission at I.

Note: This subdivision only represents a first approximation. Each part of the source is more or less screened. A further subdivision would imply more calculations, and the apparent accuracy obtained in this way would hardly agree with the precision of the original source data.

The source radiates noise uniformly. The sound power levels of S_1 and S_2, respectively, are determined as:

$$L_W(\Phi) + 10 \lg \frac{\text{subsource length}}{\text{overall source length}}$$

Variations in directivity along the overall source are unknown and neglected here.

WORKSHEET NO. 3

Source (no. j): Stone Crusher, S'
Immission point: I
Transmission path: via 40 m long screen

f_c	Hz	63	125	250	500	1000	2000	4000	8000	Cf section
L_W ΔL_Φ $L_W(\Phi)$	dB re 1 pW dB dB re 1 pW	112	113	117	113	111	110	106	98	3.1
ΔL_d	dB	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	4.2
ΔL_a	dB	0.0	0.0	-0.2	-0.4	-0.8	-1.4	-3.4	-11.2	4.3
ΔL_r	dB	-	-	-	-	-	-	-	-	4.4
ΔL_s	dB	-5.9	-7.5	-9.5	-11.9	-14.5	-17.4	-20*)	-20*)	4.5
ΔL_v	dB	-	-	-	-	-	-	-	-	4.6
ΔL_g	dB	3.0	-2.3	-5.0	-0.5	0.7	0.8	0.8	0.8	4.7
ΔL_i	dB	-	-	-	-	-	-	-	-	Appendix D
Other ΔL	dB	-	-	-	-	-	-	-	-	
$\Sigma \Delta L$	dB	-60	-67	-72	-70	-72	-75	-80	-87	
L_p	dB re 20 µPa	52	46	45	43	39	35	26	11	
ΔL_A	dB	-26	-16	-9	-3	0	+1	+1	-1	
$L_p + \Delta L_A$	dB re 20 µPa	26	30	36	40	39	36	27	10	L_{pA} = 45 dB re 20 µPa

Φ = 110°, $L_W(\Phi)$ as in worksheet no. 1
d = 200 m

*) limited

Example 3.

The transmission path transfer functions may be calculated as described in Examples 1 and 3 for transmission path no. 1 from S_1 to I and no. 2 from S_2 to I, respectively.

For the purpose of this example, however, the transmission path transfer functions from Example 1 and 3 are assumed to be valid and entered in Table F.7. Source sound power levels $L_W(\Phi)$ from worksheet nos. 1-3 are corrected with 10 lg 7/50 = ÷8.5 dB and 10 lg 43/50 = ÷0.7 dB, respectively, and the results are summarized in Table F.7. See also Figure 2.6, p. 16.

f_c [Hz]	63	125	250	500	1000	2000	4000	8000	A-w
$L_W(\Phi)$, S_1 [dB re 1 pW] $\Sigma\Delta L$, path no. 1 [dB]	104 -54	105 -59	109 -63	105 -59	103 -57	102 -58	98 -60	90 -67	- -
L_p, S_1 [dB re 20 μPa]	50	46	46	46	46	44	38	23	50
$L_W(\Phi)$, S_2 [dB re 1 pW] $\Sigma\Delta L$, path no. 2 [dB]	111 -60	112 -67	116 -72	112 -70	110 -72	109 -75	105 -80	97 -87	- -
L_p, S_2 [dB re 20 μPa]	51	45	44	42	38	34	25	10	44
L_p, $S_1 + S_2$ [dB re 20 μPa]	54	49	48	48	47	44	38	23	-
ΔL_A [dB]	-26	-16	-9	-3	0	+1	+1	-1	-
$L_p + \Delta L_A$, $S_1 + S_2$ [dB re 20 μPa]	28	33	39	45	47	45	39	22	51

Table F.7 Summary of results of calculations, Example 4.

Note 1: The contributions to the immission point sound pressure levels L_p, $S_1 + S_2$ from the two subsources are approximately equal at low frequencies while the most important contributions come from the "smaller", but unscreened source S_1 at mid- and high frequencies.

Note 2: The subdivision of the source leads to a 6 dB increase in calculated overall A-weighted immission point sound pressure level, L_{pA}, compared to the situation in Example 3, in which the source was represented by only one monopole. Partly screened sources should always be divided into at least a screened and an unscreened subsource.

Note 3: The overall effect of the screen with finite length calculated in this example (source subdivision) is a 7 dB L_{pA} reduction relative to the unscreened situation in Example 1. As a comparison the infinitely long screen yielded a 14 dB L_{pA} reduction (Example 2).

F.5 Example 5

Determine L_{pA} at the immission point with the screen of final length present, taking the contribution from the reflection from the 12 m high building shown in Figure F.1 into account.

In this example a third contribution from reflections from the building shown in Figure F.1 is included with the contributions from the subsources from Example 4. A mirror source is introduced, cf Figures F.1-2. See also Note 1 below.

$L_W(\Phi)_m$: The transmission path (no. 3) from the source S to the immission point I via the building facade has the direction $\Phi' = 45^\circ$, cf Figures 4.4.2 and F.1. $L_W(\Phi)_m$ is determined by means of equations (3.1.1) and (4.4.2) applying L_W from Table F.1, ΔL_Φ, for 45° from Table F.2, and $\rho = 0.8$. The results are entered in worksheet no. 4.

ΔL_d:
ΔL_a:
ΔL_g:
ΔL_r:
ΔL_s:
ΔL_v:
ΔL_i:

The horizontal distance between S_m and I is 260 m, cf Figures F.1-2. All calculations of ΔL_d, ΔL_a, and ΔL_g are analogous to those in Example 1. The results have been summarized in worksheet no. 4. $\Delta L_r = \Delta L_s = \Delta L_v = \Delta L_i = 0$.

The contributions from transmission paths nos. 1, 2, and 3 have been summarized in Table F.8 (cf Table F.7 and worksheet no. 4) and added on an energy basis, equation (2.2).

WORKSHEET NO. 4

Source (no. j): Stone Crusher, S

Immission point: I

Transmission path: no. 3: via reflecting facade

f_c	Hz	63	125	250	500	1000	2000	4000	8000	Cf section
L_W	dB re 1 pW	114	116	118	116	114	113	109	99	
$\Delta L_{\Phi'}$	dB $+10 \lg \rho$	-3	-3	0	-2	-3	-3	-2	-2	
$L_W(\Phi)$	dB re 1 pW	111	113	118	114	111	110	107	97	3.1
ΔL_d	dB	-59.3	-59.3	-59.3	-59.3	-59.3	-59.3	-59.3	-59.3	4.2
ΔL_a	dB	0.0	0.0	-0.3	-0.5	-1.0	-1.8	-4.4	-14.6	4.3
ΔL_r	dB	-	-	-	-	-	-	-	-	4.4
ΔL_s	dB	-	-	-	-	-	-	-	-	4.5
ΔL_v	dB	-	-	-	-	-	-	-	-	4.6
ΔL_g	dB	3.6	-1.4	-5.1	-1.1	1.0	1.1	1.1	1.1	4.7
ΔL_i	dB	-	-	-	-	-	-	-	-	Appendix D
Other ΔL	dB	-	-	-	-	-	-	-	-	
$\Sigma \Delta L$	dB	-56	-61	-65	-61	-59	-60	-63	-73	
L_p	dB re 20 µPa	55	52	53	53	52	50	44	24	
ΔL_A	dB	-26	-16	-9	-3	0	+1	+1	-1	
$L_p + \Delta L_A$	dB re 20 µPa	29	36	44	50	52	51	45	23	L_{pA} = 57 dB re 20 µPa

$\Phi' = 45°$

d = 260 m

Mirror source with $L_W(\Phi)_m = L_W + \Delta L_{\Phi'} + 10 \lg \rho$.

At 63 and 125 Hz, condition 4.4.6 is not fulfilled. Even if the mirror source contribution is omitted at these frequencies, L_{pA} remains unchanged.

Example 5.

f_c [Hz]	63	125	250	500	1000	2000	4000	8000	A-w
Path no. 1 [dB re 20 µPa]	50	46	46	46	46	44	38	23	50
Path no. 2 [dB re 20 µPa]	51	45	44	42	38	34	25	10	44
Path no. 3 [dB re 20 µPa]	55	52	53	53	52	50	44	24	57
Added (2.2), paths 1-3	57	54	54	54	53	51	45	27	58
ΔL_A [dB]	-26	-16	-9	-3	0	+1	+1	-1	-
L_{pA} [dB re 20 µPa]	31	38	45	51	53	52	46	26	58

Tabel F.8 Contributions from transmission paths nos. 1-3 and immission sound pressure level L_{pA}, Example 5.

Note 1: If equation (4.4.1) had been used instead of the mirror source considerations above, a correction ΔL_r = 10 lg (1 + 0.8) = 2.6 dB should have been added to the transfer function from Example 1. This would have led to a contribution via the reflection: L_{pA} = 58 + 2.6 ~ 61 dB re 20 µPa representing approximately 4 dB overestimation compared to the result in Table F.8. The difference is due to a combination of increased transmission path length and directional characteristics.

Note 2: The contribution from path no. 3 is the most important in Table F.8. This illustrates the importance of an effective screening of this transmission path.

APPENDIX G

G. SUPPLEMENTARY LIST OF SYMBOLS

I_h	Hypothetical immission point (Figure C.4).
M	Point on screen, Δh_m below T (equation C.1).
M_j M_k M_q	Point M on screens nos. j, k, and q (Figure C.3).
RH [%]	Relative humidity of the air.
S_h	Hypothetical source position (Figure C.4).
T_j	Point T on screen no. j (Figure C.3).
i	Index indicating internal (scattering).
j	Index indicating screen no.
k	No. of screen yielding highest elevation of line IM_j (Figures C.3-4).
n	Total number of screens (Figure C.2).
q	No. of screen yielding highest elevation of line SM_j (Figures C.3-4).
t [^oC]	Temperature of the air.
Δd_i [m]	Length of transmission path through installation (Appendix D).
Δh_m [m]	Vertical distance from top T of screen to point M (equation C.1).
ΔL_i [dB]	Correction due to internal scattering (Appendix D).
ΔL_{Ai} [dB]	Correction due to A-weighting in octave band no. i (Appendix A).
ΔL_s [dB]	Correction due to screening.
$\Delta L_{sq,h}$ [dB]	Correction due to screening by screen no. q in hypothetical situation (equations C.2-3).
α_i [dB/m]	Coefficient describing effect of internal scattering in industrial plant (Appendix D).