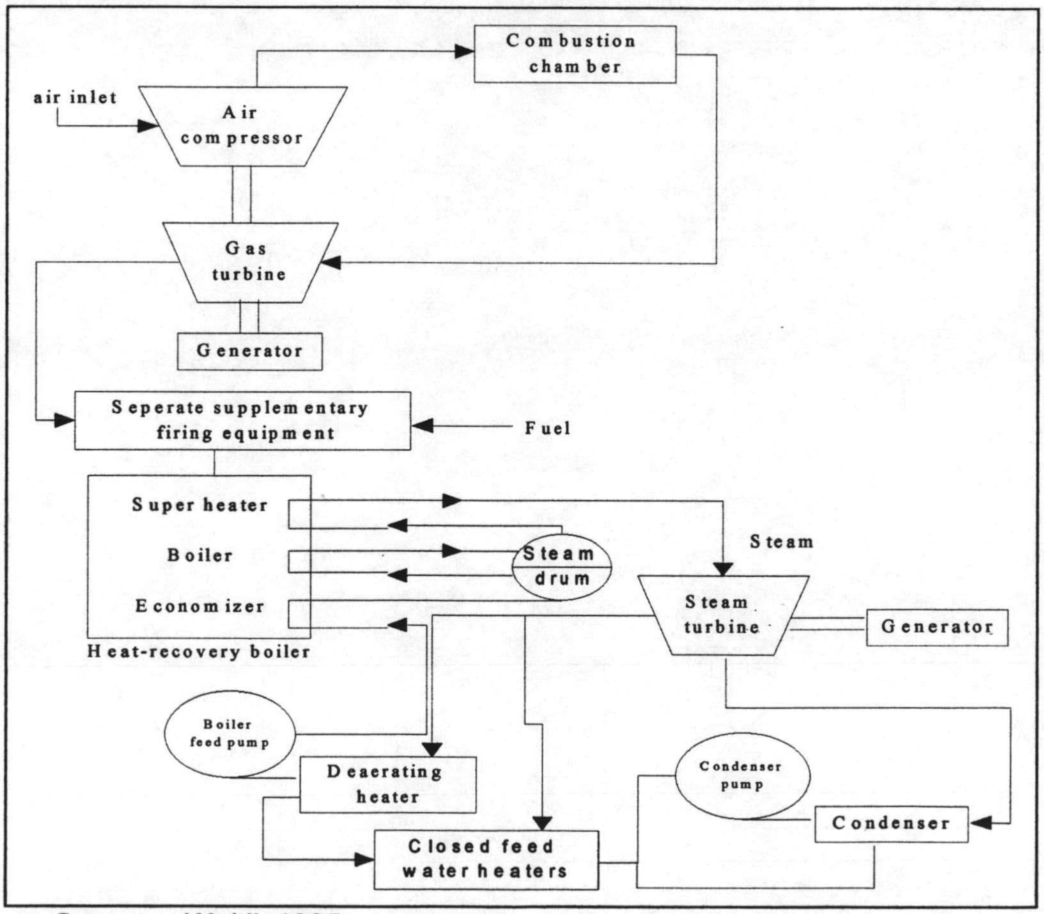
Chapter II
Literature Review

2.1 Industrial Noise Characteristic

Industrial noise characteristic is considered by two main sources of sound that emitted from sound source in factory. One is the harmonization of sound emitting from several sources or noisy machines. The other is the typical sound, according to specific frequencies, sound levels, and periodic characteristics, propagating from each equipment. There are four major groups of industrial noise sources.(Patrick, 1977)

- Electromechanical machines such as motors and generators that is dominated by periodic components.
- Combustion processes sources such as furnaces.
- Fluid motion such as fan, compressors, and steam pressure relief valves that is made the random broad-band sound and the highest level causing by high-speed movement of air or fluid.
- Impact machines such as punching, hammers, and stamping .

2.2 General Noise Source from Combined Cycle Power Plant



Source : Wakil, 1995

Figure 2-1 The combined cycle and the heat recovery steam generator

Combined cycle power plant are those which have both gas and steam turbine supplying power to the network. The idea of combined cycles has grown out of the need to improve the simple Brayton's cycle efficiency by utilizing the waste heat in the turbine exhaust gases without fuel filling. Regeneration reduces the heat lost up the stack down from some 70 to 60 percent of the energy input. The sole purpose of a regeneration is to improve efficiency. It does not increase the power output. The regeneration made increasing efficiency and power by stationary and large quantity of energy leaving for steam turbine. A combined cycle power plant is the joint operation of the gas turbine at the "hot end" (1100°C-1650°C) and the steam turbine at the"cold end" (540°C-650°C). Besides both high efficiency and high power outputs, combined cycle are characterized by flexibility, quick part-load starting, suitability for both base-load and cyclic operation, and a high efficiency over a wide range of loads. They have the potential of using coal as well as synthetic and other fuels. Their obvious disadvantage is in their complexity, as they in essence combine two technologies in one power plant complex. The general noise source of simple combined cycle system are consisted of air compressors, combustion chambers, gas turbines, heat recovery boilers (including with economizer, boiler, steam drum, superheater), steam turbines, condensers, pumps, closed feedwater heaters, deaerating heaters, and electric generators as shown in Figure 2-1. (Wakil, 1995)

2.3 Definitions

2.3.1 Noise and Sound

Sound is defined as any pressure variation that the ear can detect.

Noise is concerned with sounds which annoy us and may have a long-term physiological effect on an individual. (Lara Sáenz and Stephens, 1986)

2.3.2 Logarithm and Antilogarithm

Logarithm is defined by equation 2.1, and Antilogarithm, the inverse of the logarithm, is defined by equation 2.2. (Patrick, 1977)

$\log_a c = b$ is equal to $a^b = c$ ....(2.1)

$\log a = b$ is equal to $\text{antilog } b = a$ ....(2.2)

2.3.3 Decibel, dB, is a logarithm to the base ten of the ratio of a quantity referenced to a base reference quantity as shown in the following equation. (Howard, n.d.)

$$\text{Decibel} = 20 \log_{10} \left(\frac{\text{pressure}}{\text{reference pressure}} \right) \text{ dB} \qquad \text{........(2.3)}$$

2.3.4 Decibel Addition

Its can be described by this equation or estimated following step 1-3. (Bies and Hansen, 1988)

$$L_p(\text{total}) = 10 \log_{10} \left(\sum_{i=1}^{n} 10^{L_{Pi}/10} \right) \text{ dB} \qquad \text{.........(2.4)}$$

Step 1 : Determine the difference between the two levels to be added.(L_1 ,and L_2)

Step 2 : Find the no. L_3 corresponding to this difference in the table.

Step 3 : Add the no. L_3 to the highest of L_1 and L_2 to obtain the resultant level.

Table 2-1 The decibel addition value.

Numerical Difference Between L_1 and L_2	L_3 Amount Added to the highest of L_1 and L_2
0 to 1	3
2 to 4	2
4 to 7	1
7 to 10	0.5
more than 10	0

Source : Howard, n.d.

2.3.5 Sound Power Level(PWL) and Sound Pressure Level(SPL)

The energy that causes the air particles to vibrate is called sound power, described the acoustical power radiated by a given source with respect to the international reference of 10^{-12} watt as equation 2.6. Though PWL cannot be measured directly, as the acoustical power is emitted by a source, the air particle compress and expand around atmospheric pressure; thus, what are actually measured with a sound level meter (SLM) are changes in sound pressure. Therefore, both PWL and SPL are associated with sound power using the relationship as equation 2.7. (Bies and Hansen, 1988) PWL came from SPL from spherical measurement surface used as equation 2.8. (Patrick, 1977)

$$SPL = 10 \log_{10} (p^2/p_0^2) \quad \text{dB re } p_0 \quad \text{dB} \qquad ....(2.5)$$

$$PWL = 10 \log_{10} (W/W_0) \quad \text{dB re } W_0 \quad \text{dB} \qquad ....(2.6)$$

$$L_p = L_w + K \quad \text{dB} \qquad ....(2.7)$$

$$L_w = L_p + 20 \log_{10} d - 11 \quad \text{dB} \qquad ....(2.8)$$

2.3.6 Sound absorption is the attenuation of sound decay with the absorber material. Sound decay outdoors in free field is shown by equation 2.9, sound decay indoors within enclosures is described in reverberant field by equation 2.10. (Egan, 1972)

$$\text{Free field} \quad I = W/4\pi r^2 \quad \text{dB} \qquad ....(2.9)$$

$$\text{Reverberant} \quad I = W/A \quad \text{dB} \qquad ....(2.10)$$

There are 6 dB decay from doubling distance under free field conditions, little or no decay with distance in non-added absorption room under reverberant field, and an effective decay with added absorptive material under reverberant field in figure 2-2.(Egan, 1972)

2.3.7 Frequency Analysis and 1/1 Octave Band Analysis.

Sound, which is heard by human receptors, has overall frequency range from 20-10,000 Hz. They are ranked into interval of frequency that is called octave band. Octave band filter is widely used for frequency analysis. "Octave" is the term describing the relationship between the upper frequencies with the ratio of two lower frequencies, as below; (Bionetics Corporation, 1981)

$$f_u = 2f_l \qquad ....(2.11)$$

Since it is conventional to use a logarithm scale for plotting frequencies, the center frequency(f_c), between the lower and upper frequency of a octave band is shown as below;

$$\log_{10} f_c = (1/2) \cdot (\log_{10} f_l + \log_{10} f_u) = \log_{10} (f_l f_u)^{1/2} \quad \text{........(2.12)}$$

$$\text{Thus,} \quad f_c = (f_l f_u)^{1/2} \quad \text{........(2.13)}$$

Thus, 1/1 octave band analysis has the center frequency (f_c) as the equation 2.14.

$$f_c = \sqrt{2}\, f_l \quad \text{.........(2.14)}$$

Table 2-2 The center frequency band

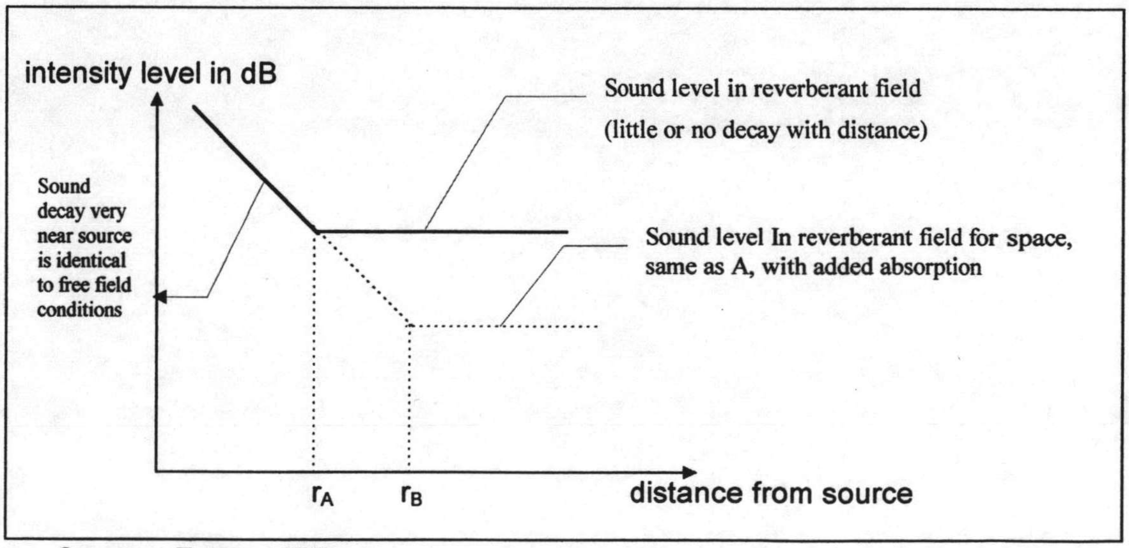
f_l (Hz)	22.4	45	90	180	355	710	1400	2800	5600
f_u (Hz)	45	90	180	355	710	1400	2800	5600	11200
f_c (Hz)	31.5	63	125	250	500	1000	2000	4000	8000

Source : Bionetics Corporation, 1981

Table 2-3 A-weighted level response collected band level with added level in this table.

Octave band, Hz	31.5	63	125	250	500	1000	2000	4000	8000
A-weighted correction	-39	-26	-16	-9	-3	0	+1	+1	-1

Source : Bionetics Corporation, 1981



Source : Egan, 1972

Figure 2-2 Sound decay outdoor in free field and indoors in reverberant room

2.3.8 Outdoor Sound Propagation

Outdoor sound propagation is commonly described in three components: source or emission , transmission path, and receiver or immission. Source emits sound power that can be measured in the vicinity of source as sound levels, propagating outward along the path from emission to immission and finally all source of sound can be combined at the receiving point. Sound diminishes with distance as it diverges from its source directively or indirectively to receiving point. There are many of effective parameter along the path such as air absorption attenuation, ground reflection or attenuation, another obstacle object in its environments. The basic equation of outdoor sound propagation is described as below; (ISO, 1993) The combined attenuation are divergence attenuation, air absorption and atmospheric attenuation, obstacle reflecting attenuation, barriers attenuation, and ground effect attenuation.

$$L_p(r) = L_w - 20 \log (d/1m.) + DI_{revr} - 10 \log_{10} (\Omega /4\pi) -11 -A_{combined,revr} \quad ....(2.15)$$

2.3.9 Geometrical Spreading of Sound Energy

Sound intensity falls off with the distance from source is the acoustic power radiates into space depending on the shape of the wave-front. The radiating surface is limited so the plane-waves gradually diverge with the distance into spherical waves. Because the surface area of wave-front increases as the square of the distance from the source, every time that the distance doubles the surface increases four times. The total power being the same through any wave-front surface, the intensity or power per unit area decreases to one-fourth.

For cylindrical waves, the surface increases linearly with the distance, so the intensity reduces only by $10 \log_{10} 2 = 3$ dB for each doubling of the distance. (Bies and Hansen, 1988)

2.4 Noise Prediction Model

Noise prediction model is used to predict the environmental noise from industrial area or factories, according to the general equation of sound propagation outdoor. Many countries have the same concept to develop their equation to suit their local conditions. International Standard Organization, Germany, Scandinavian countries and Netherlands used the same concept to develop their prediction equation. Those countries have different symbols to define parameters in thier equations. They also have a different way to find the input data depending on their local noise source and some environmental parameter such as PWL calculation from mechanical power database of DIN-standard, SPL determinate by SPL measurement on ISO-standard, and sound intensity measurement or database of industrial machine sound power. However, Murray Hodgson and Davis N.Lewis (1994) and Stephen Dance (1994) try to reduce the error of predicted data from their model using the different method to make their own PWL of machine database.

The general equation was already shown in 2.15 as sound propagation outdoors. There are several applications of the general equation for industrial noise pollution control. The International Organization Standardization published the general equation for noise prediction in ISO 9613 Part II that was known as the initial equation making noise prediction model being described in 2.4.1. It was used in the United State of America and others countries under the general requirements and some modified parameter to match their local conditions. (ISO, 1993)

In Germany, they use the equation published by Verein Deutscher Ingenieure report no.2714 (VDI, 1985) outdoor sound propagation standard for developing the industrial noise prediction model as shown in 2.4.2. Not only are there differences in calculating of air absorption attenuation from the general equation specially on the relationship of wind speed, wind direction, temperature gradients attenuation but also the difference of the source directivity. That means, there are specific requirements in order to make their noise prediction model.

In Scandinavian countries, they are launching the Norskfork project to research their own industrial noise prediction model. They divided their project into several parts and assigned each part to members to make a complete version of each part and then returned it back to joint into main project, coding the application program of prediction model. There are the transfer function equations and a PWL of noise source determination equation in 2.23. There is no difference from initial equation of international standard equation except the vegetation attenuation and internal scattering attenuation. The sound source determination is studied by Nordic Project in 1983, they suggested four methods in order to determine the noise source in terms of PWL. There are short distance method, long distance method, large source method, and Stüber method. (Nordtest Project, 1989)

In Netherlands, they applied the general equation to set up the measuring and calculating guides for industrial noise. There are three main classes of methods; simplified methods, standard methods, and specialist methods. They classified the specific parameters of each class before determining the noise emission, transfer rating, and other specific parameters. Emission determination of the source consist of position of sound source, source in an acoustical free field, source above ground, source high in wall of building, source high in wall of building near the ground, source on the roof of a building high location, source on the roof of a building near roof surface, stack source, and concentrated source in between reflecting and screening objects. And also determined the meteorological condition by means of wind speed and wind angle by day and by night. (ESSO Steenkool Technologie B.V., 1982)

Oil Companies Material Association (OCMA) distributed a report of the measurement and calculation method for equipment noise of industrial or factory noise determination. They described the measurement into four part as small source methods, large source methods, vibration measuring methods, and contouring methods. Their equation depends on the international organization of standardization report no. 3744. (The engineering equipment and materials users (EEMUA), 1988)

From all literature reviews, it can be concluded the concept of the industrial noise prediction model, generally used; the same equation of noise transmission path attenuation, which takes into account divergence attenuation, air absorption attenuation, reflecting obstacle attenuation, screening obstacle attenuation, other types of the obstacle attenuation, ground effects, and meteorological attenuation. In term of noise source, they used a different equation that relies on their situation, even if its come from the same basic equation described in ISO 3744, the determination of the PWL of sources; Engineering method, and ISO 3746; Surveys method. (ISO, 1979) Therefore the accuracy of the model would mainly rely on the precision of the noise source determination. Although each model has a different sound source determination equation, the equations can be classified as point source and area source. They provided the groups of calculation method for noise source depending on the measurement surface. All of the equations in the international organization of standization reports explained the uncertainty level of noise source determination about ±1.5 dB for the engineering method and about ± 3 to 5 dB for the surveys method.

Murray Hodgson and David N.Lewis (1994) tried to reduce the error of the sound source determination from ISO 3746, which is commonly used to determine the noise of sources on site measurement. They distributed their studied in the Acoustical Society of America, concentrating on the environmental-correction factors for typical industrial workrooms. They mainly used the international standard report no. 3746 and 3744 for studying the effective correction factors of industrial source in workrooms. They found the Sabine theory was not suitable to determine the PWL of noise source in workrooms because there may be no diffusion inside the rooms, relating to the room shape and the distribution of surface absorption. The ray-tracing prediction model and 1:8-scale-model was purposed to decrease an inaccuracy factors of Sabine theory. It can make the effective correction factors accurate upto 2 dB in case of omnidirectional and directional sources.

2.4.1 General Prediction Model : ISO 9613 Part II

General noise prediction model was derived from ISO 9613 Part II (ISO,1993) is shown as a general equation in order to develop noise prediction model. This reports described a general method specified for calculating the attenuation of sound during propagation outdoors in order to predict the environmental noise levels at a distance from a variety of sources. Its can calculate the noise levels under changing environmental conditions favorable to propagation from sources of known sound power. These conditions are for downwind propagation that is under ± 45° wind direction from source to receiver and approximately between 1 to 5 meters per second wind speed, measuring at 3 to 11 meters above the ground. The noise sources are generally defined by the point source therefore the extended sources are could be a set of cells, each having own sound power and directivity. A group of point sources may be introduced by an equivalent point source situated in the center of the groups. If the source have approximately the same strength and height above the local ground plane, the same propagation conditions to the immission point, and the distance "d " from the single equivalent point source to the immission exceeds two times the largest diameter D of the equivalent area of the sources ($d > 2D$). If the distance "d " is smaller than 2D ($d \leq 2D$), or the propagation conditions are different, the source could be divided into no. of cells. The basic equations are shown in equation 2.16. The A-attenuation during propagation from point source to receiver introduced by the equation 2.17. The effective PWL is reported by equation 2.18. For non-directional point source DC is set to 0 dB. For point source that is situated into restricted solid angles sound source DC could be explained by equation 2.19.

$L_{downwind} = L_{WD} - A$ ....(2.16)

$A = A_{div} + A_{atm} + A_{ground} + A_{refl} + A_{screen} + A_{misc}$ ......(2.17)

$L_{WD} = L_W + DC$ ....(2.18)

$DC = DI + K_0$ ....(2.19)

2.4.2 Deutsche's Noise Prediction Concept

They used the calculated concept as the same as the international standard, launching the Verein Deutscher Ingenieure report no. 2714 (VDI,1985), Outdoor sound propagation, and they have the additive correction for large source, directivity index, absorption attenuation in term of temperature and humidity, vegetative obstacle, residential obstacle, meteorological effects on ground attenuation, and wind direction effects.

$L_s = [L_w + DI + K_0] - [D_s + \Sigma D]$ ....(2.20)
(DI in table2-4 and figure 2-3)

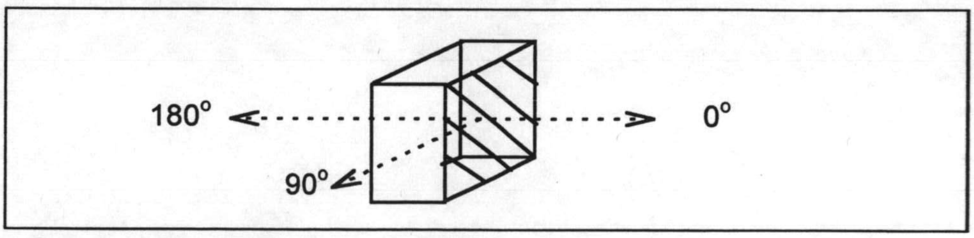
$K_0 = 10 \log_{10} (4\pi/\Omega)$ dB ....(2.21)

$\Sigma D = D_L + D_{BM} + D_D + D_G + D_E$ dB ....(2.22)

Table 2-4 Source directivity correction for sound power determination

Plane wall : If $0^\circ \le \phi < 85^\circ$ then $DI = -3 + (3\phi/42.5)$ dB If $85^\circ \le \phi \le 135^\circ$ then $DI = 3 - 10 \log (0.4(\phi - 90^\circ) + 3)$ dB If $135^\circ < \phi \le 180^\circ$ then $DI = -10$ dB
Plane wall with openings : If $0^\circ \le \phi < 45^\circ$ then $DI = 4$ dB If $45^\circ \le \phi < 85^\circ$ then $DI = 6 \log ((90^\circ - \phi)/10)$ dB If $85^\circ \le \phi \le 135^\circ$ then $DI = -2 - 6 \log (0.4(\phi - 90^\circ) + 3)$ dB If $135^\circ < \phi \le 180^\circ$ then $DI = -10$

Source: VDI, 1985



Source : VDI, 1985
Figure 2-3 Direction coefficient

Table 2-5 Large source position correction

Large source measurement	Ω
Free field measurement	4π
Hemispherical measurement	2π
Wall side measurement	π
Corner measurement	$\pi/2$

Source : VDI, 1985

2.4.3 Scandinavian Noise Prediction Concept

General prediction method for environmental noise from industrial plants described procedures to be used for the prediction of noise immission in areas adjacent to industrial plants. (Kragh, Andersen and Jakobsen, 1982) Basically the prediction method is an octave band method and assumed each real noise source can be represented by an equivalent monopole source. The noise source data are described in other reports worked out within the Nordforsk frame project. Only transmission path attenuation is estimated by means of additive corrections for spherical divergence, air absorption, reflections from vertical surfaces, screening, vegetation, ground effects, and in-plant scattering. These environment correspond to moderate downwind or slight temperature inversion.

$$L_{p(tij)} = L_w(\Phi_t)_{ij} + \Sigma\Delta L_{tij} \qquad ....(2.23)$$

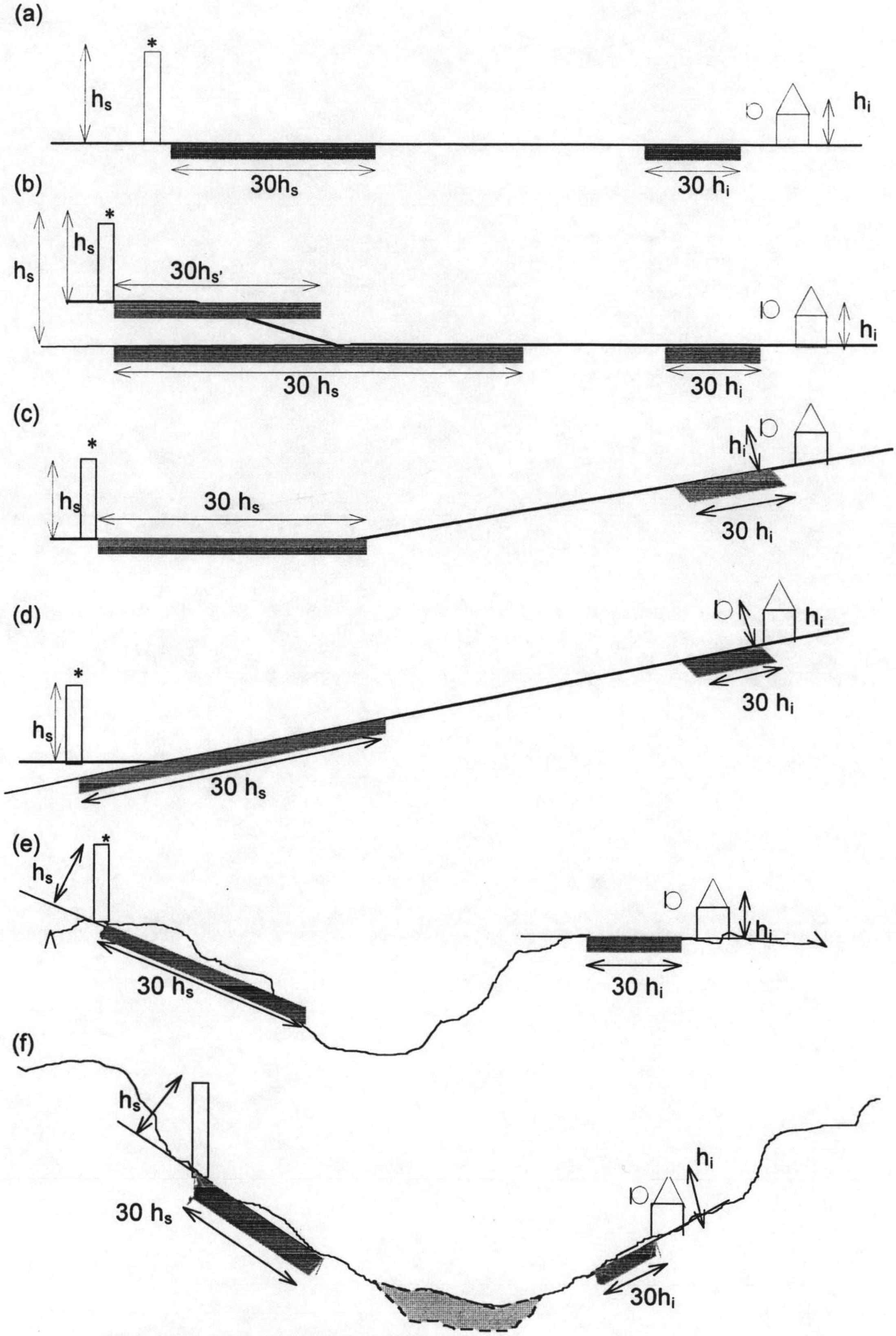
Noise source directivity is explained by the following equation 2.24,and the correction for directional effects was based on the international standard report no.s 3744. If the short distance method is used determining noise source, directional effects cannot be taken into account ,hence ΔL_Φ is equal to 0 and that means $L_w(\Phi)$ is equal to L_w. (Kragh, Anderson and Jakobsen, 1982) The emission determination method is divided into four method as short distance method, long distance method, large source method, and stüber method. (Jakobsen and Andersen, 1983), and transfer function are shown in equation 2.25.

$$L_w(\Phi) = L_w + \Delta L_\Phi \qquad ....(2.24)$$

$$\Sigma\Delta L = \Delta L_d + \Delta L_a + \Delta L_r + \Delta L_s + \Delta L_v + \Delta L_i + \Delta L_g \qquad ....(2.25)$$

The equation 2.25 will be described a large source method. In case of large source method. It was necessary to correct the PWL by directivity index , ΔL_Φ,as shown in equation 2.24. Stüber method was applied for PWL determination of noise source. If screening obstacle has more than one screen or being thick screen, they could be selecting the effective screening. The selection method bases on the effective height, h_e , of each individual single screen. Finally, there are two effective screen left in addition to calculate the screening attenuation. If the ground surface is not horizontal and level, the effective height of emission, h_s , and immission, h_i , was changed to be estimated as the Figure 2-4.

2.4.4 Guide for measuring and calculating industrial noise published by the Dutch Ministry of Public Health and Environmental Hygiene. (ESSO Steenkool Technologie B.V., 1982) This guideline is described the method for measuring and



Source : Kragh, Andersen and Jakobsen, 1982

Figure 2-4 Sectional views illustrating the definitions of emission point heights and immission height in hilly (a) to (f) calculating noise from industrial area or factories. According to this guideline, there are three main classes of methods; simplified methods, standard methods, and specialist methods.

2.4.4.1 Simplified methods

$$L_i = L_{pA} - C_n - \Delta C_h - C_{ref} \qquad \text{.........(2.26)}$$

$$(C_{ref} = 20 \log_{10} (r/r_{ref}))$$

2.4.4.2 Standard methods.

There are the correction terms of the ambient noise correction and the meteorological conditions. The height of source, used in calculation equation, is very important when the effective screen is presented. It was defined as 2/3 of real source height. The basic formula is present in equation 2.27.

$$L_i = L_{WR} - \Sigma D \quad \text{dB} \qquad \text{.........(2.27)}$$

Table 2-6 The correction term C_h for distance between source to immission, r $\geq$ 100 m., if r < 100 m. the values in the table must be multiplied by r/100.

Receiving area	Height m.	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000-8000 Hz
Absorbent	1.5	0	0	+2*	+6	+5	+1	0
	3	0	0	+1*	+3	0	0	0
	5	0	0	0	0	0	0	0
	10	0	0	-3	-1	0	0	0
	20	0	0	-3	-1	0	0	0
Hard	all	all frequencies 0 dB						
$\Delta C_h = C_{h(\text{conditions immission point})} - C_{h(\text{measuring conditions reference point})}$								
* For long distances more than 500 meters : if h = 1.5 meters then correction is equal -6 if h = 3 meters then correction is equal -3								

Source : ESSO Steenkool Technologie B.V., 1982

Table 2-7 Procedure step of the Standard method

Step no.	Procedures
B1	Direct measurement of the noise immission
B2	Determination of immission by measurement of source power and transmission calculation for concentrated sources
B3	Determination of immission by means of measuring the source power and calculation of the transmission for extensive sources (Stueber method)
B4	Determination of the immission levels by means of source measurements and transmission calculations. (adapted measuring plane or according to ISO: reference plane)

Source : ESSO Steenkool Technologie B.V., 1982

2.4.4.3 Specialist methods.

There are the correction terms of the ambient noise correction and the meteorological conditions according to the procedure steps as shown in table 2-8. The height of source is very important parameters when the effective screen is presented. It was defined as 2/3 of real source height. The basic formula is present in equation 2.28; the C2 procedures of concentrated sources. The basic function of rating of the sound transmission, C8, is described in equation 2.29. The other steps do not mention in this research. (Esso Steenkool Technologie B.V., 1982)

$$L_{WR} = L_p + 10 \log_{10} 4\pi R_r^2 + D_{bodem} + a_{lu} R_r \text{ dB} \quad ....(2.28)$$

$$L_i = L_{WR} - \Sigma D \quad \text{dB} \quad ....(2.29)$$

$$\Sigma D = D_{geo} + D_{air} + D_{refl} + D_{screen} + D_{veg} + D_{site} + D_{ground} + D_{building} \text{ dB} \quad ....(2.30)$$

Table 2-8 The procedure of the specialist method

Step no.s	Procedures
C1	Direct immission measuring
Emission	
C2	Concentrated source
C3	All - round measurement (Stueber , Colenbrander)
C4	Adapter measuring plane
C5	Intensity measurements
C6	Velocity measurements
C7	Calculation building insulation
Transfer	
C8	Calculation transfer
C9	Substitution method (measure transfer)

Source : Esso Steenkool Technologie B.V., 1982

2.4.5 EEMUA (1988) distributes the measuring, and calculating procedures of the equipments noise source determination. They have a general requirement for 1/1 Octave band analysis measurement, background noise measurement, fluctuating noise measurement, testing condition and sound level meter calibration. There are many kinds of source dimensions to determine, therefore they divided source determination into three groups; small source methods, large source methods and linear source methods. However, they also offered the typical method for determining noise source using vibration measurement and contour methods for all complete plants. This procedure used only in the normal industrial area conditions such as factories or opened-air plant. It is not practicable for special anechoic or reverberant test chambers. It is important to verify the test environment to meet the requirements and must be checked as part of the procedures. The PWL of noise source is normally determined from SPL measurements on an imaginary surface enveloping the source, defined as the "measuring surface", to define the smallest possible imaginary cuboid just enclosing the source as a reference surface, which is mounted on the ground .

The preferred measuring surface is a hemisphere surfaces that could ideally be made under conditions of free field above a reflecting plane. And also there could be no other reflecting surfaces present apart on the ground, and on other sources to cause high background levels. The cuboid measuring surface is another surface using determine the noise source in according to the same conditions. The test environment correction is based on ISO 3746, could be applied into measurement when a machine is located in an enclosed space. The room constant, R, of the space in which the machine is located could be used for the purpose of this specification. The small source method has the basic equation in 2.31.

$$L_w = \bar{L}_p + 10 \log_{10} S - E_2 \quad \text{dB} \quad \text{......... (2.31)}$$

The large source method has the basic equation in 2.32 and the near-field correction, E_1, was definded in term of quotient, Q, as the measuring surface area divides reference surface area in table 2-9.The calculation of the PWL of linear source can be estimated from the following equation 2.33. The sound propagation aspects is explained in equation 2.34 and 2.35 for hemispherical radiation, estimated by only the distance attenuation.

$$L_w = (\bar{L}_p - E_{1Q}) + 10 \log_{10} S - E_2 \quad \text{dB} \quad \text{......... (2.32)}$$

$$L_w = (\bar{L}_p - E_{1R} + 10 \log_{10} S + 10 \log_{10} b) - E_2 \quad \text{dB .... (2.33)}$$

($2\pi r$ for a cylinder and πr for a half cylinder, m^2)

$$L_p = L_w - 10 \log_{10} (2\pi r^2) \quad \text{dB} \quad \text{..........(2.34)}$$

$$L_p = L_w + 10 \log_{10} (1/2\pi r^2) + 4/R \quad \text{dB} \quad \text{..........(2.35)}$$

Table 2-9 The near-field correction factors, E_1 for small and large source method.

Quotient, Q	E_{1Q} , dB
0.9 < Q < 1	3
0.7 < Q < 0.9	2
0.4 < Q < 0.7	1
0.0 < Q < 0.4	0

Source : EEMUA, 1988

Table 2-10 The near-field correction factors, E_1 for linear source method.

r/l ratio	E_{1R} , dB
r/l < 0.08	2
0.08 < r/l < 0.24	1
0.24 < r/l < 0.4	0
0.4 < r/l < 0.58	-1
0.58 < r/l < 0.8	-2
Remark : For r/l ratio is greater than 0.8 the source can be treated as a small source.	

Source : EEMUA, 1988

2.4.6 Environmental Correction Factors for Typical Industrial Workrooms.

The determination of PWL in ISO 3744 requires an essential free-field test environment and ISO 3746 is used for machinery in situ measurement and different test environment. By means of no less than 4 dB standard deviations are anticipated for errors in terms of the no. of measurement points, the shape of the measurement surface and the correction factors at particular points. The environmental correction factor that is calculated from this standard relies on the assumption of diffuse sound field. In fact, the sound field in typical industrial workrooms is not diffuse, for reason depended on the room shape, the distribution of surface absorption, and the presence of fittings. And also the source directivity index affects the noise levels around the source greater than free-field noise levels. In practice, the directivity index is very difficult to measure and usually not known. This study try to correct an error from this term. In order to investigate the accuracy of the standard's environmental correction method and obtain more accurate effective correction factors for typical workroom configurations, the ray-tracing predictions and 1:8-scale-model measurements in case of omnidirectional and directional sources was introduced.

Murray Hodgson and David N.Lewis (1994) made several methods to reduce the error of noise source determination from SPL measurement, by refering to the surveys method. The PWLs from their experiment are compared with the reference PWLs from sound intensity measurement in order to calibrate the ray-tracing predictions and 1:8-scale-model. The field measurement were not conducted as part of a rigorous scientific study, however, several conclusions that were drawn from the data were reasonably useful for accuracy of noise source determination. The effective environmental correction factor from the calibrated sound power source. From the experiment it was found that the Sabine steady-state theory cannot estimate an accurate environmental correction factor in large irregular rooms, and the Sabine reverberation theory consistently underestimated the effect of the local environment on measured noise levels.

In the test room, increasing the ceiling absorption above a single machinery-noise source can reduce noise levels at 1 meter more than 2 dB, depending on source directivity. Thus, to investigate the effective correction factors, the typical configurations, predictions, and 1:8-scale-model were undertaken. Ray-tracing prediction techniques were applied to make the model workroom with different ceiling heights, a 3 cubic meters predicting surface around the source and absorption materials to cover the entire inner surface of the test room. They found the ceiling height strongly affected the prediction value. The scale-model tests uses an existing rectangular 1:8-scale-model room in a semi-anechoic chamber to determine the typical factors. To investigate the factors, they used the specific absorptive materials for adjusting the diffusion state of the room, two different roof heights, 5 and 10 meters, controlled air absorption conditions, and real time analyzer.

The results of the field, ray-tracing, and scale-model methods, consider the accuracy with standard procedures for only omnidirectional sources, but significantly underestimates in vertically directional sources. An error of accuracy about 1 dB applies to the omnidirectional sources with the exception at low frequencies where the error is greater. In case of the vertically directional sources, the accuracy significantly decreases with source directivity. Although, the geometry and fittings did not affected the factors inside the 3 room with different floor dimensions, each with an adjustable 4 stage roof height but the source directivity, ceiling height, absorption, and survey-surface meaningfully affected that factors. It was not consequently assumed that a diffuse sound field exists in order to estimate environmental correction factors for ray-tracing or other prediction models with more extreme geometries, fitting densities, and distribution workrooms.

2.5 Power Plant Noise Prediction Model

In this study, we followed the same general equation for power plant noise prediction model, classified some essential parameter to meet the local conditions, and measured noise source data based on the modal assumption and other guidelines from ISO 3746 (ISO, 1979), ISO 9613 Part I and II (ISO, 1993), ISO 6190 (ISO,1988), the noise levels at the boundaries of factories and commercial premises (Jenkins, Salvidge and Utley) and the factory noise prediction from plane source. (Yamamoto, Takagi and Hiramatsu, 1990)

Some source equations and transmission parameters are different from the Danish Acoustical Laboratory Technical report no. 32 (Kragh, Andersen and Jakobsen, 1982) and the ISO 9613 Part II (ISO, 1993). The differences were applied in field work study in order to investigate the relative parameters using the recommended documents.

2.5.1 Model Assumption

The specific assumption of this model are explained in the table below.

Table 2-11 Model assumption

Factors	Conditions
Wind speed and wind direction Temperature and relative humidity range[*1)]	less than or equals 2 m/s and downwind condition were recommended 0-45 °C and 10-100 % RH
Obstacles condition Reverberation condition	no vegetation obstacles no reverberation inside the effective obstacle building
Noise source type	industrial noise source and not including noise source from impact machine or impulse noise and factors operating 24 hours (e.g. power plant, refinery plant).
Environmental conditions	point source measurement condition only for outdoor environment (K = 0)
Screen obstacle specification	all conditions are specified in the table 2-16
Reflecting obstacle specification	all conditions are specified in the table 2-14, only one reflecting obstacle, and relies on the case conditions.
Ground factor (G-type)	all G-type of ground are specified in table 2-20
[*1)] Temperature could be considered in range of 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45 °C and also relative humidity could be considered in range of 10 - 100 % increasing by 10%	

2.5.2 Primary Equation of Prediction Model

The basic equation, 2.36, of the noise prediction model is mainly modified from the International Standard Organization report no. 9613 Part II (ISO, 1979), and Danish Acoustical Laboratory technical report no. 32 (Kragh, Anderson and Jakobsen, 1982) that is containing coupling terms of data inputting in addition to predict immission noise level at one receiving point. The input data consists of two main terms; sound level of noise source in decibel and the correction factor which is the summation of outdoor sound propagation in decibel.

$$SPL = PWL + \Sigma\Delta L \quad dB \qquad ....(2.36)$$

The PWL of the noise source can be calculated from the equations that is explained by means of emission part in 2.5.2.1.The corrections terms is calculated using equation as shown as transmission part in 2.5.2.3.

2.5.2.1 Emission part

Noise source determination for sources at the combined cycle power plant is calculated by the determination of PWL using the SPL measurement from the basic equation of ISO 3746. (ISO, 1979) The sound source could be divided into 2 groups; point source and non-point source. Each group has the specific criteria for applying from the same concept in different measurement surface. Those criterias are the enclosure status, fitting status, practice of measurement, source dimensions, distance between source and receiving point, and directivity of source. Point source have dissimilar measurement surface according to general equation to determine PWL from SPL measurement shown in equation 2.37-2.38. Generally, point source measurement surface is a hemispherical surface, except when there have an enclosure or insulator or others design, made them looks like cubodial object.

$$PWL = (\overline{SPL}\text{-}K) + 10 \log_{10} (S/S_0) \quad dB \qquad ....(2.37)$$

$$\overline{SPL} = 10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^{n} 10^{0.1SPL_i} \right] \quad dB \qquad ....(2.38)$$

Others source can calculate by non-point source as linear source, area or plane source, solide surface source and Colenbrader method. The measurement surface of the line source is a hemi-cylinder or a quarter-cylinder surface as shown in figure 2-5 (b). Linear surface method used equation 2.39 to calculate PWL from SPL measurement. The area or plane source is mainly discussed by sources, situated inside large building coverring with enclosure wall or very large source without reflecting plane except ground and situated in short distance region, the sound energy directly emitted from the wall of the building. PWL can calculate from integral small energy per area of the wall by point source concept (Bies and Hansen, 1988) as rewrited by Yamamoto, Takagi and Hiramatsu (1990) in equation (e) of table 2-12.

The solid surface and Colenbrander's methods developed from basis of point source equation for large rectangular source. Solid surface popularly used by

Yamamoto, Takagi and Hiramatsu (1990) for cooling tower or large industrial source. Measurement surface seems to be an non anglular box on the ground as shown in figure 2-6. (Hassall, Zaveri and Phill, 1988) This method can use both SPL inside and outside enclosure wall. Measured SPL near the wall inside building can calculate SPL close to the wall outside environment by subtraction with transmission loss data by equation 2.43 and 2.44 for in situ measurement transmission loss data and databook, repectively. Solid surface can calculate by equation 2.45 and 2.41. Colenbrander's method developed (EEMUA, 1988) for calculating PWL of noise source of horizontal area surrounding the sound source. SPL at contour line surrounding noise source can calcuate PWL of noise source by equation 2.42.

$$PWL = SPL + 10\log_{10}(\tan^{-1}(b/2R)) - 8 \quad dB \qquad ......(2.39)$$

$$PWL = SPL + 10\log_{10}S \qquad ......(2.40)$$

$$S = AB + 2H(A+B) + 2\pi R(H+R) + 2\pi(A+B) \qquad ......(2.41)$$

$$PWL = SPL + 10\log_{10}(2S_c) - 1 \quad dB \qquad ......(2.42)$$

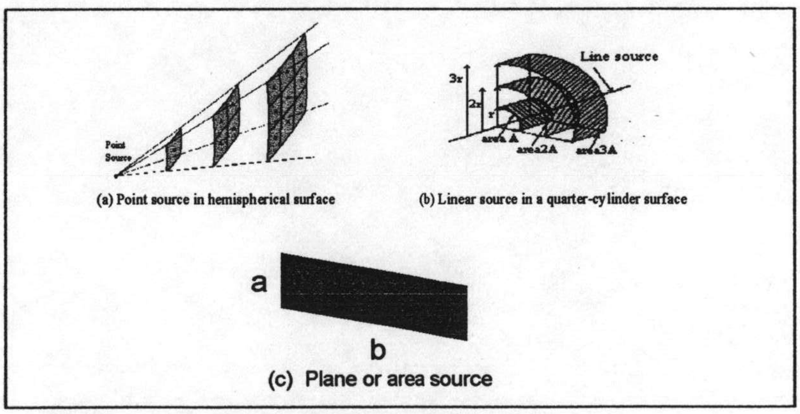
$$SPL_{out} = SPL_{in} - TL \qquad ......(2.43)$$

$$SPL_{out} = SPL_{in} - TL - 6 \qquad ......(2.44)$$

Table 2-12 The equation for calculating area source

Limitation	Equation
$r \le a/\pi$	$PWL = SPL \quad dB$ (a)
$a/\pi \le r \le b/\pi$	$PWL = SPL + 10\log_{10}(a/R) - 5 \quad dB$ (b)
$r \ge b/\pi$	$PWL = SPL + 10\log_{10}(ab/R^2) - 10 \quad dB$ (c)
PWL of plane source, d is direct distance to the plane, and non vertical direction $k = 2-(4/\pi)$, $A=a/d$, $B=b/d$	$PWL = SPL - 10\log_{10}\psi - 8 \quad dB, \quad \varphi = \int_{x_1}^{x_2}\int_{y_1}^{y_2}\frac{dxdy}{x^2+y^2+d^2}$ (d) $\varphi = \frac{(A+\sqrt{1+A^2})(B+\sqrt{1+B^2})}{A+B+\sqrt{1+A^2+B^2+kAB}}$ (e)

Source : Yamamoto, Takagi and Hiramatsu, 1990



(a) Point source in hemispherical surface (b) Linear source in a quarter-cylinder surface (c) Plane or area source

Source : Hassall, Zaveri and Phill, 1988

Figure 2-5 Noise source propagation path

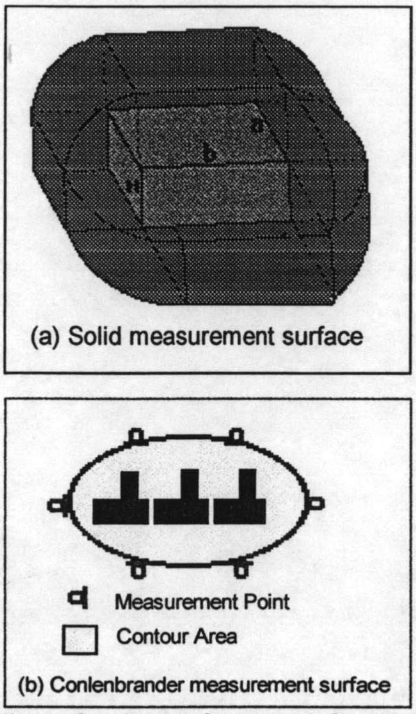


Figure 2-6 Description of solid surface and Conlenbrander surface

2.5.2.2 Immission part

Immission part of the model is the point that recepted enegy, emitted from source during sound propagation outdoors. This part is considered by SPL_p that is the results of prediction model by means of "SPL" at the present time. In this study, the immission point height is 1.5 meters to calibrate and verify power plant noise prediction model.

2.5.2.3 Transmission part

This part can be described in terms of the outdoor sound propagation correction which is calculated by the summation of divergence attenuation, air absorption by means of temperature and relative humidity attenuation, reflecting obstacles attenuation, screening obstacles attenuation, ground effects attenuation.

$$\Sigma\Delta L = \Delta L_{div} + \Delta L_{air} + \Delta L_{ref} + \Delta L_{scr} + \Delta L_{grd} \quad \text{dB} \qquad ....(2.45)$$

(a) Divergence attenuation correction, ΔL_{div}

Divergence attenuation is a correction factors which takes into account of sound energy radiated by the spherical source. In general, divergence attenuation is calculated using the equation 2.46 when the distance between source and receiving point, d, is 80 % more than the different between source height and receiving height, H_s-H_i,, equation 2.47 is used. This term is always less than zero and frequency independent. (Kragh, Andersen and Jakobsen, 1982)

$$\Delta L_{div} = -10 \log_{10} 4\pi R_d^{\ 2} \quad \text{dB} \qquad ....(2.46)$$

$$d >> (H_s - H_i): \Delta L_{div} \approx -20 \log_{10} d - 11 \quad \text{dB} \qquad ....(2.47)$$

(b) Air absorption attenuation correction, ΔL_{air}

Air absorption attenuation is a correction factors which takes into account of the attenuation by the energy dissipation and molecular relaxation in air by means of air temperature in degree Celsius and relative humidity in percentage. This attenuation affects the distance between source and immission point, R, more than 200 meters and frequency dependent. (Kragh, Andersen and Jakobsen, 1982) Attenuation coefficient is given by the ISO9613 Part I, (ISO, 1993) depending on local temperature and relative humidity.(Temperature range: 0 °C to 45 °C and Relative Humidity range: 10 to 100 % with 10 increment) The temperature and relative humidity range depends on modal assumption.

$$\Delta L_{air} = -\alpha_a R_d \quad \text{dB} \qquad ....(2.48)$$

(c) Reflecting obstacles attenuation correction, ΔL_{ref}

The effects of sound reflections from obstacles are treated by simple acoustical mirror considerations from couple source, real source, S, and mirror source, S_m , at the same time to one receiving point. This attenuation is always equal or greater than zero, and could be fulfilled all of specification in model assumption and reflecting obstacle conditions in table 2-13. If the properties of transmission paths no.1 and 2, figure 2-7 are approximately equal the mirror source is omitted, and instead a correction by means of equation 2.49. If there is an essential differences between the transfer functions of transmission paths no. 1 and 2, figure 2-7 and conditions specified in table 2-13, are all fulfilled, a mirror source S_m has to be introduced. But this our study could not be covered this case. The obstacle coefficient were shown in table 2-14. (Kragh, Andersen and Jakobsen, 1982)

$$\Delta L_{ref} = 10 \log_{10} (1+\rho) \quad \text{dB} \qquad ....(2.49)$$

(d) Screening obstacles attenuation correction, ΔL_{scr}

Screening attenuation is to identify all screening obstacles between source and immission point, represented by regularly shaped and thin screen. It eventually followed the main procedure step in Figure 2-8. The obstacles could have be all of specific conditions in table 2-15, but it was not fulfilled the correction may be set equal to zero. The correction is always less than or equal to zero and frequency dependent. (Kragh, Andersen and Jakobsen, 1982)

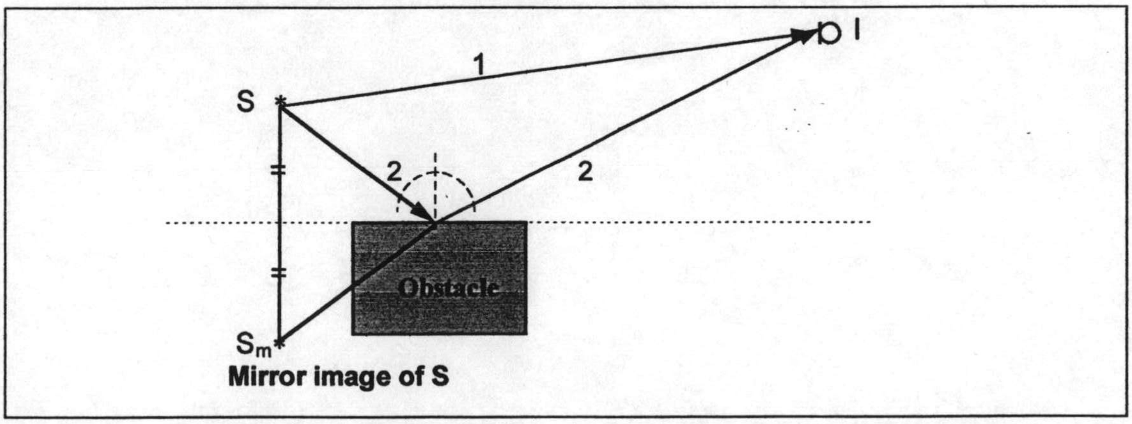


Figure 2-7 Plan of transmission paths between source and immission point.

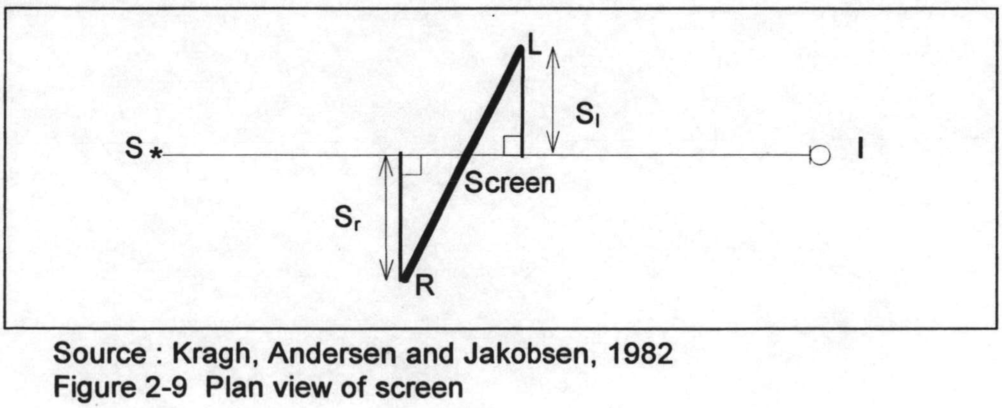
The selection of the effective screen was depending on the effective height, h_e, of the individual single screen, determined by the equation in table 2-17 and figure 2-10. There are three conditions of screen, considered by this method, thin screen, thick screen, and two screens. The single screen that is thin and $h_e \geq 0$, calculating by equation in table 2-18.The thick screen which is the distance of thick screen, d_{12} , 80 % more than the distance between source and receiving point, d, separating into two effective screen. They could be followed the two screen equation in table 2.17 before take into the main equation. If there are more than two screen present at plane V, having effective heights, $h_e \geq 0$, the two most effective of these are selected as described in step 1-4 and illustrated in figures 2-11 to 2-14. If no screens or at least omitted one of the screen specification, the screening attenuation is set to zero. If all screens have effective height, $h_e<0$ choose the only one smallest numerical value of δ_v . If the effective screen is very long in comparison to its height , the screening attenuation was considered by only vertical effect or N_r and N_l are equal zero. The main equation of the calculation of screening attenuation could be following step by step in table 2-18. The data input of geometrical vertical of the effective screen has shown in figure 2-10. If there is thick screen present, some parameter for horizontal transmission path is illustrated by figure 2-15.

(e) Ground effects correction, ΔL_{grd}

Basically this attenuation, ΔL_{grd} , is calculates the sum of three terms, explaining in the following table, each of which being related to the properties of different parts of the ground surface and the immission point. The ground effects attenuation mainly reckon using the equation 2.50 and table 2-21. Each of parts is relatively on 1/1 Octave band and can be more or less than 0 as amplification or attenuation. If there is an effective screen presented, including the source height and immission point height less than 5 meters, the effective height of source and immission will be replaced by the equation 2.51. Each of parts can be estimated using the equation in table 2-19, partly specified the ground factors (G) following table 2-20.

$$\Delta L_{grd} = \Delta L_{g,s} + \Delta L_{g,i} + \Delta L_{g,c} \text{ dB} \qquad ....(2.50)$$

$$\text{source height: } h = H_s + H_{e1}\,(1 - (d_{s1} / d)) \text{ dB}$$
$$\text{immission height: } h = H_i + H_{e2}\,(1 - (d_{i2} / d)) \text{ dB} \qquad ....(2.51)$$



Source : Kragh, Andersen and Jakobsen, 1982
Figure 2-9 Plan view of screen

Table 2-13 Reflecting obstacle specification

Condition no.	Specification
1	The reflecting obstacle could be "solid" plane, and acoustically hard
2	The horizontal dimension of the reflecting obstacle measured perpendicular to the transmission path could be greater than the wavelength
3	The height of the reflecting obstacle above the ground could fulfil at least one of the following criteria : 1. could be more than source height plus 0.0625 of source-obstacle distance 2. could be more than immission height plus 0.0625 of immission -obstacle distance
4	The angle of incidence could be less than 85°
5	The reflection could take place at least at a distance of wavelength from the edge of the obstacle

Source : Kragh, Andersen and Jakobsen, 1982

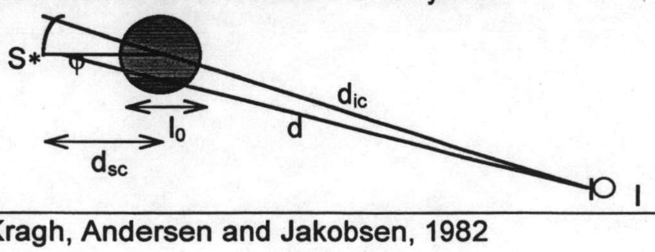
Table 2-14 Reflecting obstacle coefficient, ρ

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)	$(l_0 \sin \varphi/2)/(2d_{sc})$

l_0 : Cylinder diameter, meters

φ : Supplement to the angle between the line SC and the line IC

d_{sc} : Distance from source to middle C of cylinder



Source : Kragh, Andersen and Jakobsen, 1982

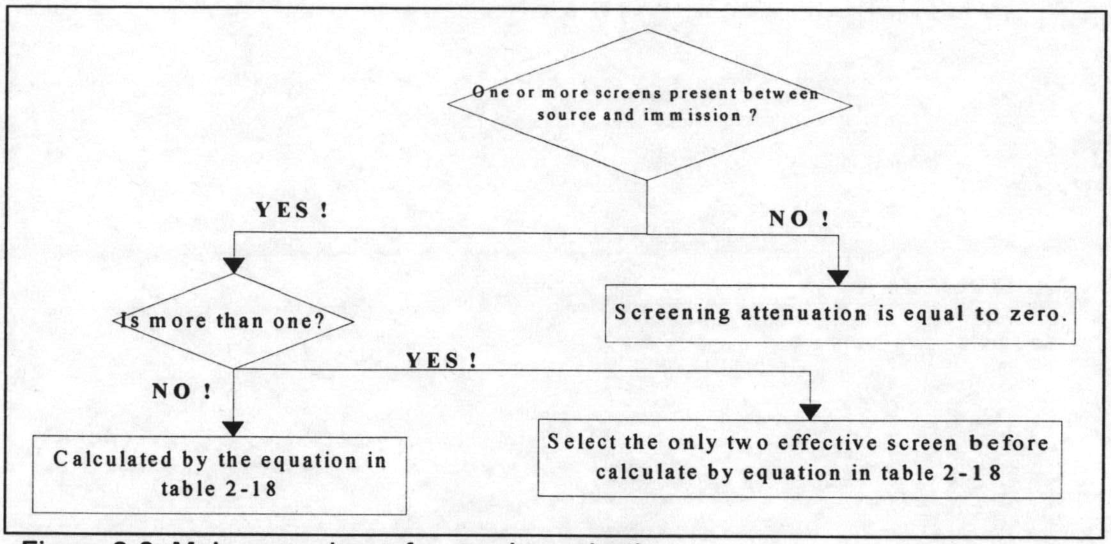


Figure 2-8 Main procedure of screening selection

Table 2-15 The screening obstacles specification

Condition no.	Specification
1	The mass of the screen could exceed 10 kg/m^2
2	There could be no slits or openings in the structure
3	The horizontal dimension perpendicular to the line between the source and the immission point could be greater than the wavelength (figure 2-9)

Source : Kragh, Andersen and Jakobsen, 1982

Table 2-16 The selecting method for more than two screen.

Step number	Selection method
1	Remove all screen for which $h_e < 0$
2	Determine for each of the remaining screen (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. $(\Delta h_m)_j = (h_e \{ 1 - \frac{1}{(1+(h_e/s_r)) + (h_e/s_l))} \}_j$ The $(\Delta h_m)_j$ is equal zero for an infinitely long screen.
3	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 I and the points M_j (j = 1...n). Choose the value k of j yielding the highest elevation angle of the line IM $_k$.
4	If the values of q and k (step 3) are equal, ΔL_{scr} is calculated as ΔL_{scr} for single screen, no. q = k . If the values of q and k (step 3) are differ, ΔL_{scr} is calculated as combined effect of screens nos. q and k in table 2.17.

Source : Kragh, Andersen and Jakobsen, 1982

Table 2-17 The calculation of the screening attenuation and more than one effective screen.

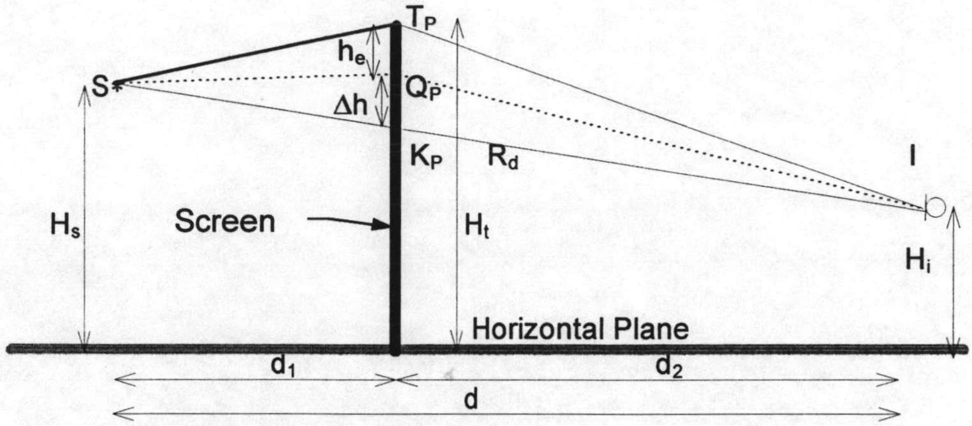
Screen	Equation for the combination of two highest effective screen nos. q and k
1	$\Delta L_{scr} = \Delta L_{scr\,q} + \Delta L_{scr\,k,h}$ $\Delta L_{scr\,sq}$: the correction calculated according to table 2.17 assuming screen no.q to be the only screen present in figure 2.14 (a) $\Delta L_{scr\,k,h}$: the 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 in figure 2.14 (a)
2	$\Delta L_{scr} = \Delta L_{scr\,q,h} + \Delta L_{scr\,k}$ $\Delta L_{scr\,q,h}$: the correction calculated according to table 2.17 assuming screen no.k to be the only screen present in figure 2.14 (b) $\Delta L_{scr\,k}$: the correction calculated assuming screen no.q to be the only screen present and the source to be a hypothetical source I_h on top of screen no. k in figure 2.14 (b)

Source : Kragh, Andersen and Jakobsen, 1982

Table 2-18 Determination step for screening correction calculation

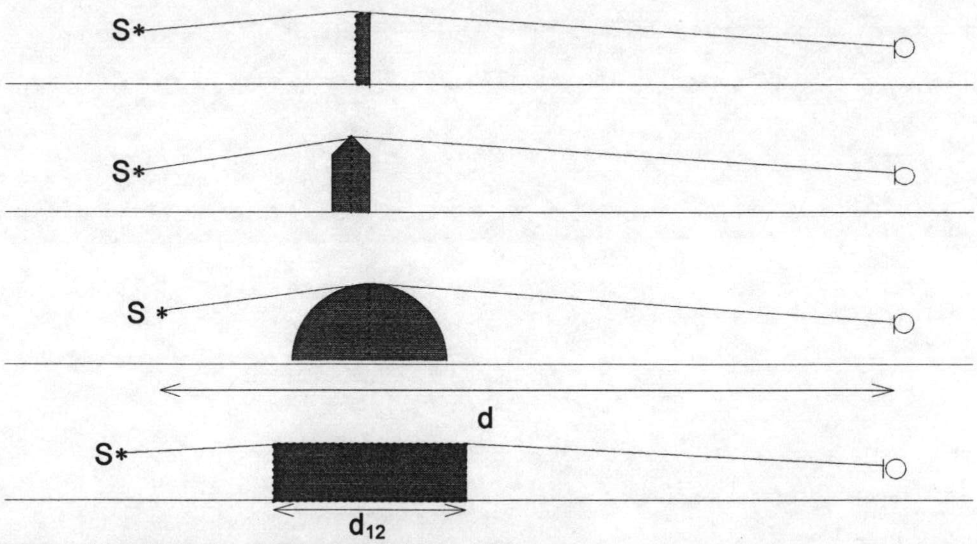
Step no.	Conditions	Equations
1. find pointK$_P$, Q$_P$,T$_P$	-	$\Delta h = d_1 d_2 / 16 d$ (m.)
	K$_P$ below T$_P$	$h_e = \lvert K_PT_P\rvert - \Delta h$ (m.)
	K$_P$ aboveT$_P$	$h_e = -(\lvert K_PT_P\rvert - \Delta h)$ (m.)
2. find δ_v	K$_P$ below T$_P$	$\delta_v = \lvert ST_P\rvert + \lvert T_PI\rvert - \lvert SQ_P\rvert - \lvert Q_PI\rvert$ (m.)
	K$_P$ above T$_P$	$\delta_v = 2(\lvert SI\rvert - \lvert SQ_P\rvert - \lvert Q_PI\rvert - \lvert ST_P\rvert - \lvert T_PI\rvert)$ (m.)
3. find δ_r, δ_l	Thin screen	$\delta_r = \lvert Sk_r\rvert + \lvert K_r I\rvert - \lvert SI\rvert$ (m.) $\delta_l = \lvert SK_l\rvert + \lvert K_l I\rvert - \lvert SI\rvert$ (m.)
	Thick or Building screen	$\delta_r = \lvert Sk_{r2}\rvert + \lvert K_{r2} I\rvert - \lvert SI\rvert$ (m.) $\delta_l = \lvert SK_{l1}\rvert + \lvert K_{l1} I\rvert - \lvert SI\rvert$ (m.)
4. find N of δ_v , δ_r , and δ_l	-	$N_v = 0.0047\ \delta_v f_c$ $N_r = 0.0047\ \delta_r f_c$ $N_l = 0.0047\ \delta_l f_c$
5. find ΔL_{scr}	$N_v \leq -0.1$	$\Delta L_{scr} = 0$ (dB)
	$N_v > -0.1$	$\Delta L_{scr} = 10\ C_h \log_{10} [(1/(20N_v +3))+(1/(20N_r +3))+(1/20 N_l +3))]$ (dB)
	-	$C_h = (f_c / 250)(H_t)$
ΔL_{scr}	$C_h > 1$ $\Delta L_{scr} > 0$ $\Delta L_{scr} < -20$	$C_h = 1$ $\Delta L_{scr} = 0$ (dB) $\Delta L_{scr} = -20$ (dB)

Source : Kragh, Andersen and Jakobsen, 1982



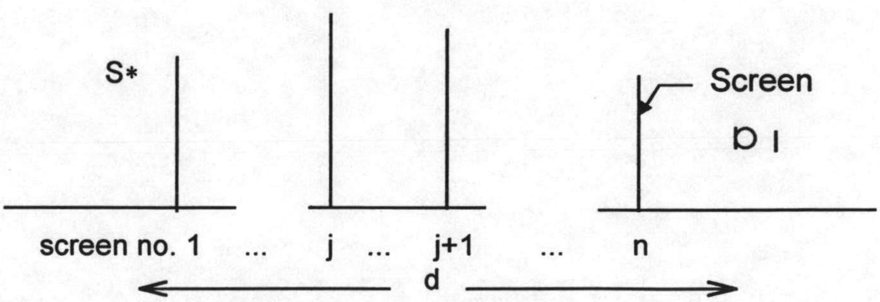
Source : Kragh, Andersen and Jakobsen, 1982

Figure 2-10 Geometrical parameter in vertical plane of screen correction



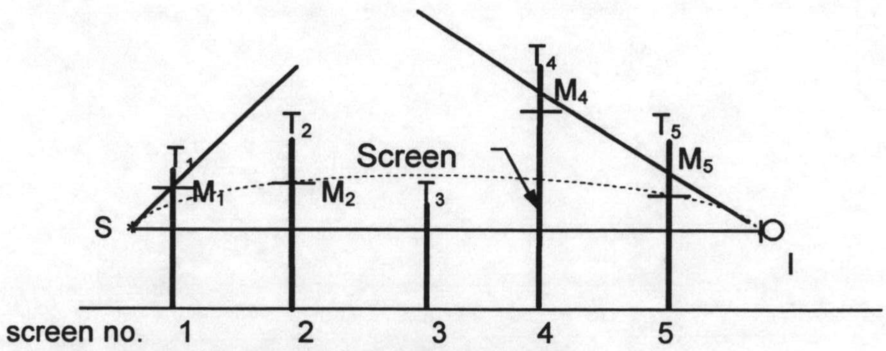
Source : Kragh, Andersen and Jakobsen, 1982

Figure 2-11 Example illustrating a building's screen representation in sectional view



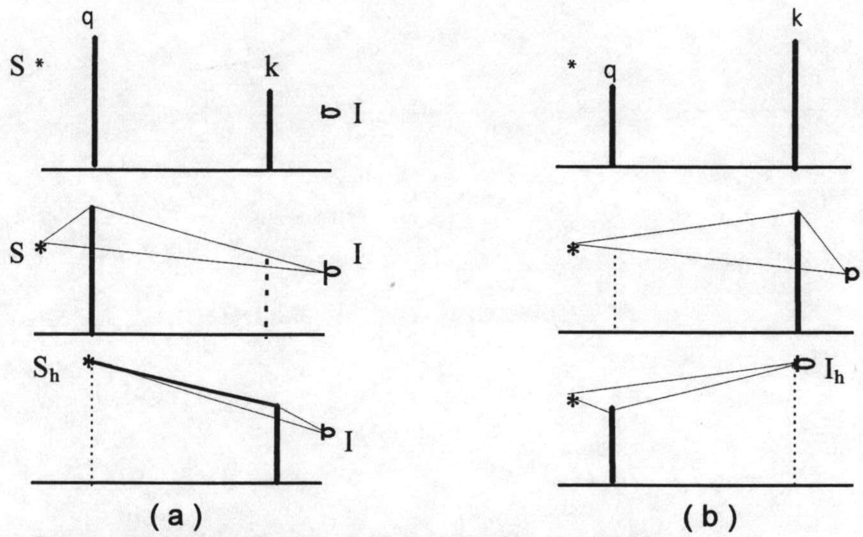
Source : Kragh, Andersen and Jakobsen, 1982

Figure 2-12 Sectional view illustrating the general situation when more than one screen intersect the vertical plane.



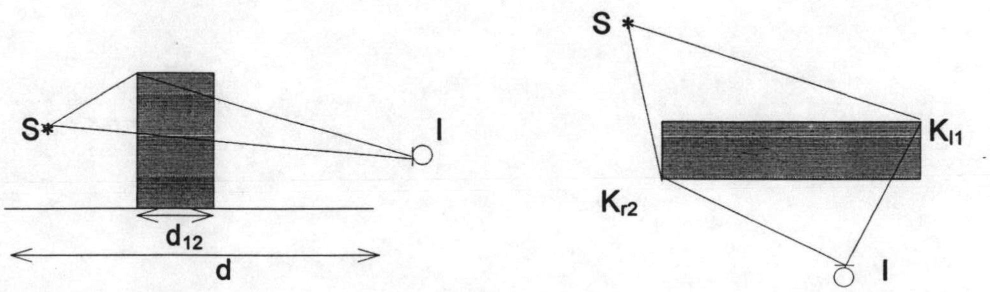
Source : Kragh, Andersen and Jakobsen, 1982

Figure 2-13 Sectional view illustrating the selection procedure. n = 5, highest elevation of SM_j is found for j = q = 1 and highest elevation of IM_j is found for j = k= 4



Source : Kragh, Andersen and Jakobsen, 1982

Figure 2-14 Sectional view illustrating the calculation of screening atenuation for two screens, nos. q and k



Source : Kragh, Andersen and Jakobsen, 1982

Figure 2-15 Example illustration for building's screen representation, particularly the horizontal transmission path differences.

Table 2-19 Definitions of different ground surface parts.

Source part (s)	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 value of 30 h_s .
Immission point part (i)	The immission point part is the part of the ground surface with the width d_i measured horizontally from three vertical projection of the immission point on the reference plane. d_i is defined as the value of 30 h_i .
Central part (c)	The central part is the part of the ground surface area situated between the source and immission point parts, respectively. The central part does not exist in case of $d < 30(h_s + h_i)$, or there are presented the source and immission parts overlap more or less.

Source : Kragh, Andersen and Jakobsen, 1982

Table 2-20 Ground surface type characterization and values of ground factors G

Ground surface type (G)	Characterization
Hard ground G = 0	Asphalt, pavement, concrete, water, and ground surfaces with many scattering obstacles are considered acoustically hard.
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 havingand acoustically porous surface.
Partly porous ground G = p/100	If a percentage porous ground (p) of the ground surface is porous and the rest is hard, the ground factor G is found by interpolation.

Source : Kragh, Andersen and Jakobsen, 1982

Table 2-21 The equations is used estimating each part of ground correction.

1/1 Octave band(Hz)	$\Delta L_{g,s}$ $\Delta L_{g,l}$ (dB)	$\Delta L_{g,l}$ (dB)	$\Delta L_{g,c}$ (Hz)
63	1.5	1.5	3m [*1)]
125	$1.5 - G_s\ a(H_s)$ [*2)]	$1.5 - G_i\ a(H_i)$ [*2)]	3m $(1-G_c)$ [*1)]
250	$1.5 - G_s\ b(H_s)$ [*3)]	$1.5 - G_i\ b(H_i)$ [*3)]	
500	$1.5 - G_s\ c(H_s)$ [*4)]	$1.5 - G_i\ c(H_i)$ [*4)]	
1000	$1.5 - G_s\ d(H_s)$ [*5)]	$1.5 - G_i\ d(H_i)$ [*5)]	
2000	$1.5(1-G_s)$	$1.5(1-G_i)$	
4000	$1.5(1-G_s)$	$1.5(1-G_i)$	
8000	$1.5(1-G_s)$	$1.5(1-G_i)$	

*1) If $d \le 30(H_s + H_i)$ then $m = 0$
If $d > 30(H_s + H_i)$ then $m = 1 - [(30(H_s + H_i))/d]$
If $m < 0$ then $m = 0$

*2)
$$a(H) = 1.5 + 3e^{[-0.12(H-5)^2]}(1 - e^{(-d/50)}) + 5.7e^{(-0.09H^2)}(1 - e^{(-2.8x10^{-6}d^2)})$$

*3) $b(H) = 1.5 + 8.6e^{(-0.09H^2)}(1 - e^{(-d/50)})$

*4) $c(H) = 1.5 + 14e^{(-0.46H^2)}(1 - e^{(-d/50)})$

*5) $d(H) = 1.5 + 5e^{(-0.9H^2)}(1 - e^{(-d/50)})$

Source : Kragh, Andersen and Jakobsen, 1982