Report

Nord2000 – Prediction of Outdoor Sound Propagation. Amendments to Report AV1106/07 revised 2014

Performed for Vejdirektoratet

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1. Introduction

Because of Word compatibility problems, it has been found that the Nord2000 documentation report AV1106/07: Proposal for Nordtest Method: Nord2000 – Prediction of Outdoor Sound Propagation [1] can no longer be updated with a satisfactory layout result. Particularly the layout of equations is the cause of problems. In connection with earlier revisions of the method, an updated version of the report has been published after each revision. The latest report was published in 2014.

In the future, an amendment report will be produced after each revision of the method containing a description of changes made in relation to the documentation report from 2014. In the amendment report auxiliary functions defined in [1] will be used in the equations without further explanation.

This amendment report describes changes introduced as a result of the 2018-revision.

2. Amendments

2.1 Section 5.5.2 Equivalent Linear Sound Speed Profile

The following paragraph shall be inserted before the paragraph: When $|\xi|$ becomes ...

To avoid numerical problems in the Nord2000 model, ξ calculated by Eq. (18) shall be limited downwards to -0.2. The corresponding value of c_0 is determined by Eq. (20) in [1] using that the corresponding value of $\Delta c/\Delta z = -0.2\, c_0$.

2.2 Section 5.5.4 Calculation of Ray Variables for a Direct Ray

The following equation and paragraph shall replace Eq. (43).

$$d_{SZ} = \sqrt{z_S\left(\frac{2}{|\xi'|} - z_S\right)} + \sqrt{z_R\left(\frac{2}{|\xi'|} - z_R\right)} \qquad \textbf{(43)}$$

If the value in the brackets under any of the square roots becomes negative, the result of the corresponding square root is set equal to zero.

2.3 Section 5.7.1 Diffraction of a Wedge with Finite Surface Impedances

The following paragraph shall be inserted before the paragraph: The function $\hat{E}_v(A(\theta_n))$ ...

After the 2018 revision of Nord2000, the definition of Q_2 to Q_4 (where Q_4 is the product of Q_2 of Q_3) shown above in Eq. (80) is only used for Sub-model 3 (Non-flat Terrain without Screening Effects) described in Section 5.10. In Sub-models 4 to 6 for terrain with screening effects, it has previously been assumed that the impedance of the two wedge faces adequately could be represented by the impedance of the segments closest to the wedge top. In the 2018 revision, it was found that this is not always the case.

Therefore, Q_2 to Q_3 are in these sub-models determined as weighted average reflection coefficients of all relevant segments as described in the inserted Annex G (Amendment 2.16). This implies that each reflection coefficient may be based on more than one impedance. The change in determination of the reflection coefficient described in Annex G affects the description of Sub-Models 4 to 6 in Sections 5.13 to 5.15 in excess of the basic diffraction Sections 5.7.1 to 5.7.4. It should be pointed out that the changes described in Annex G apply only to the wedge face reflections of the screen, whereas the reflection coefficient calculation in terrain segments before, after or between screens are unchanged.

2.4 Section 5.7.3 Diffraction of Two Wedge-Shaped Screens

$j2\rho f\tau$ shall be replaced by $j\omega\tau$ in Eqs. (97) and (98).

2.5 Section 5.7.4 Diffraction of Two Wedge-Shaped Screens

$j2\rho f\tau$ shall be replaced by $j\omega\tau$ in Eqs. (102) and (103).

2.6 Section 5.10 Flat Terrain with One Type of Surface

In Eqs. (120) and (121), 10 log shall be inserted between the sign of equation and the following sign of brackets (... = 10 log (...).

2.7 Section 5.12 Sub-Model 3: Non-Flat Terrain without Screening Effects

The following text shall be inserted at the end of the paragraph: The travel time τ_S between source ...

The height h''_{SCR} is defined in Section 5.5.2 by Eq. (22).

2.8 Section 5.13 Sub-Model 4: Terrain with One Screen Having One Edge

The following paragraph shall be inserted after the first paragraph:

As already mentioned in Section 5.7.1, in this section, the reflection coefficients of the screen wedge faces shall be determined as described in Annex G instead of as described below. This apply only to the wedge face reflections of the screen, not to the reflection coefficients of terrain segments before and after the screen.

2.9 Section 5.14 Sub-Model 5: Terrain with One Screen Having Two Edges

The following paragraph shall be inserted after the first paragraph:

As already mentioned in Section 5.7.1, in this section, the reflection coefficients of the screen wedge faces shall be determined as described in Annex G instead of as described below. This apply only to the wedge face reflections of the screen, not to the reflection coefficients of terrain segments before and after the screen.

2.10 Section 5.15 Sub-Model 6: Terrain with Two Screens

The following paragraph shall be inserted after the first paragraph:

As already mentioned in Section 5.7.1, in this section, the reflection coefficients of the screen wedge faces shall be determined as described in Annex G instead of as described below. This apply only to the wedge face reflections of the screens, not to the reflection coefficients of in terrain segments before, after and between the screens.

2.11 Section 5.21.2 Determination of a Primary Edge of a Secondary Screen

In the third paragraph the variable Δl shall be replaced by Δl_0.

2.12 Section 5.21.4 Determination of Terrain Flatness

In the paragraph following Eq. (317) at the end of the second line, the phrase "where sub-model 3 for non-flat is" shall be replaced by "where sub-model 3 for non-flat terrain is".

2.13 Section 5.23.6 FresnelZoneW

The following text shall be inserted at the end of the paragraph "If the receiver is in the shadow zone ... by Eq. (347)":

To avoid numerical problem in Eq. (347) for high values of h_S or h_R in proportion to the value of d, an argument of -1 of the function arccos should be used, if the argument becomes less than -1.

2.14 Section 5.23.20 Other Auxiliary Functions

The title of Table 10 shall be changed to the following:

Sections where other auxiliary functions are described.

2.15 Annex B (Informative)

The whole text of Annex B in [1] shall be replaced by the following text:

Determination of the Simplified Terrain from the Actual Terrain

This annex describes a method for approximating a real terrain shape defined on basis of digital elevation data and ground surface information by a simplified segmented terrain. The main purpose is to reduce the calculation time by reducing the number of segments in the calculation but also to increase the stability of the calculation by avoiding too many very short segments.

In the method the simplification is made for the terrain profile and the ground surface profile independently. This is done to avoid that the simplified terrain profile is affected by ground surface properties.

The first step is to simplify the terrain profile. The terrain profile shown in Table 11 is derived from the terrain profile definition in Table 1 in [1].

Point no.	Horizontal distance	Vertical height
1	x_1	z_1
2	x_2	z_2
...	...	...
nxz-1	x_{nxz-1}	z_{nxz-1}
nxz	x_{nxz}	z_{nxz}

Table 11
Terrain profile.

The method is based on “the maximum deviation principle” in which the ground point P having the maximum perpendicular distance r_{max} to the line between the first and the last ground point P_1 and P_2 will become a new ground point in the segmented terrain. The principle is illustrated in Figure 44.

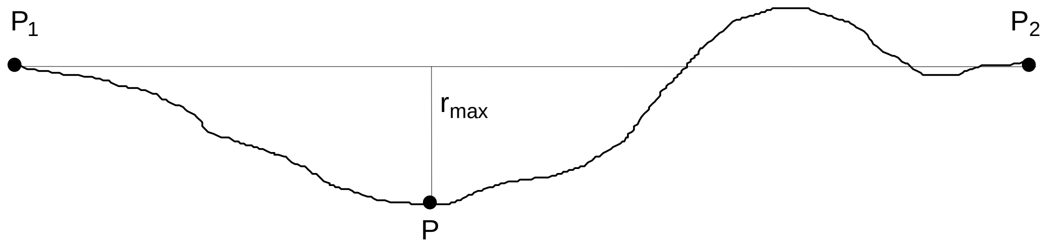

Figure 44
“Maximum deviation principle” used to determine a new ground point.

In the first step the ground point P between P_1 (equal to the source ground point S_G) and P_2 (equal to the receiver ground point R_G) is determined according to the maximum deviation principle. If r_{max} is below a specified limit the terrain is defined as being flat but if not, P will become a new ground point in the simplified terrain shape which now consists of two straight segments P_1P and PP_2.

In the next step the process is repeated for the two ground shapes P_1 to P and P to P_2. r_{max} is determined for each of these two shapes and the point corresponding to the largest value of r_{max} will become the next ground point in the simplified shape which now consists of three segments.

This process may be repeated to any degree of perfection but each time a new point is added, an existing segment is replaced by two new segments. As the calculation time of the Nord2000 propagation model will increase strongly with the number of segments, this should only be repeated until deviations between the real and the segmented terrain are within acceptable limits.

It is recommended that additional extra ground points are added to the segmented terrain until the following requirements are fulfilled:

- The maximum deviation r_{max} fulfils a distance dependent requirement as e. g. shown in Eq. (393).
- The maximum number of segments is $N_{ts,max}$. $N_{ts,max} = 10$ seems to be a reasonable choice for unscreened propagation whereas up to 20 segments may be necessary in of screened propagation.

$$r_{max} \leq \begin{cases} 0.1 & d \leq 50 \\ 0.002d & 50 < d < 500 \\ 1 & d \geq 500 \end{cases} \qquad \textbf{(1)}$$

The next step will be to simplify the ground surface profile. The ground surface profile shown in Table 12 is derived from the terrain profile definition in Table 1 in [1].

Point no.	**Horizontal distance**	**Ground flow resistivity**
1	x_1	σ_1
2	x_2	σ_2
...	...	...
nxz-1	x_{nxz-1}	σ_{nxz-1}
nxz	x_{nxz}	NA

Table 12
Ground surface profile.

The ground surface profile in Table 12 can be simplified to consider only 1, 2 or 3 ground impedance classes as defined in Table 13. In case of two ground surface types the impedance classes are reduced to D (porous ground) and G (hard ground) and in case of 3 to B, D, and G. For many calculation purposes the use of two ground surface types in considered sufficient. The use of one ground surfaces will for most purposes be a too rough approximation but it can be used for special purposes when no detailed information is available or for e. g. testing the sensitivity to the ground surface information. In both cases the representative impedance class should not necessarily be D, but the class estimated to represent to the overall terrain.

Impedance class	**Number of ground surface types**		
	3	**2**	**1**
A	B	D	D
B	B	D	D
C	B	D	D
D	D	D	D
E	D	D	D
F	G	G	D
G	G	G	D
H	G	G	D

Table 13
Reduction of the number of ground surface types.

A more practical simplification scheme is given by Table 14 in which the values of σ do not necessarily have to be equal to the representative σ-values of impedance classes A-H.

<table>
<tr><th rowspan="2">Ranges of ground flow resistivity σ in kPasm^{-2}</th><th colspan="3">Number of ground surface types</th></tr>
<tr><th>3</th><th>2</th><th>1</th></tr>
<tr><td><125</td><td>31.5</td><td rowspan="2">200</td><td rowspan="3">200</td></tr>
<tr><td>125-800</td><td>200</td></tr>
<tr><td>>800</td><td>20000</td><td>20000</td></tr>
</table>

Table 14
Reduction of the number of ground flow resistivities σ into 1 to 3 representative σ-values.

Whether or not the number of impedance classes are reduced, the simplification is done by removing all points (no. i) in the ground surface profile, where the preceding point (no. i-1) has the same impedance class.

After simplification of the terrain profile in Table 11 and the ground surface profile in Table 12, the last step is to merge the simplified ground surface profile into the terrain profile. The merged profiles shall be given in the terrain profile definition format of Table 1 in [1] where roughness is assumed to be zero. A point in the ground surface profile having a value of x that does not exist already in the terrain profile is inserted merged terrain profile. For an inserted point the value of z is determined by linear interpolation between the nearest points on each side of x having a defined value of z.

The outlined procedure above shall only be considered a proposal. If a more calculation time efficient procedure can be developed, such a method can be used instead. In general, it is recommended to simplify the terrain as much possible before performing calculations, not only because of the reduction calculation time but to avoid instabilities in the behavior of the Nord2000 method. A too high increase in the level of details when defining the terrain information may not only increase the calculation time but will in many cases fail to provide to a higher the calculation accuracy and may in extreme cases lead to an unstable method.

2.16 Annex G

Annex G shall be inserted after Annex F in [1].

Determination of Equivalent Reflection Coefficients used in the Calculation of the Propagation Effect over Wedge Surfaces of Screens

This annex defines the equivalent real reflection coefficient $Q_e(f)$ and describes how to determine the average value of Q_e of a wedge leg or an elongated wedge leg in screen effect calculations.

When screening effects in calculation methods are due to man-made structures like buildings or walls, the reflective properties of the wedge surfaces are very often characterized by the energy reflection coefficient (or absorption coefficient) because the surface impedances are not available. In such cases, the described method in Sections 2.16.1 through 2.16.4 can optionally be replaced by the simplified approach described in 2.16.5. The simplified approach is most applicable when the wedge surfaces are vertical or have an inclination where the sound do not propagate along the surfaces. On the other hand, the simplified approach should not be used for natural ground surfaces.

2.16.1 G.1 Definition of the Equivalent Real Reflection Coefficient

The equivalent real reflection coefficient Q_e is defined by the value that fulfils Eq. (404) where $Q_c(f,\psi_G,R,Z_G)$ is the complex spherical-wave reflection coefficient and f is the frequency, ψ_G is the grazing reflection angle, R is the distance between the screen top and receiver (or source) and Z_G is complex ground impedance of the ground. Right side of the equation is the ground effect ΔL_G due to the ground reflection in a flat surface with finite impedance when source and receiver is at and above the surface, respectively. The geometrical setup for screen wedge is shown in Figure 9 in [1]. On the source side of the screen top $\psi_G = \beta\text{-}\theta_S$ and $R = R_S$ and on the receiver side $\psi_G = \theta_R$ and $R = R_R$.

$$20log\big(1 + Q_e(f, \psi_G, R, Z_G)\big) = 20log|1 + Q_C(f, \psi_G, R, Z_G)| \qquad \textbf{(404)}$$

Therefore, $Q_e(f)$ can be determined by Eq. (405) and the result will be a real number between -1 and 1.

$$Q_e(f, \psi_G, R, Z_G) = |1 + Q_C(f, \psi_G, R, Z_G)| - 1 \qquad \textbf{(405)}$$

The concept of the equivalent real reflection coefficient Q_e can only be used if there is no or very little phase interaction with other complex variables. By example, the concept cannot be used to predict ground effects if both source and receiver is above the surface because the phase effect at the ground reflection will interfere with the phase effects of the travel time differences between the direct and reflected ray.

The advantage of using a real Q_e instead of the complex Q_c is that it is more straight-forward to limit Q downwards to avoid extreme ground attenuations and to determine averages of Q.

In the method, $Q_e(f)$ shall for each frequency be determined by Eq. (405) but when a value of $Q_e(f)$ becomes lower than -0.369, the value -0.369 shall be used instead. This will limit the ground effect to a value no more than 10 dB below the ground effect of a hard surface (Q=1 corresponding to ΔL_G=+6 dB).

2.16.2 G.2 Determination of the Wedge Leg Ground Effects for One Screen with One Edge (Sub-model 4)

Before the 2018-revision of the Nord2000 method, the calculation of the diffraction of a finite impedance wedge assumed that the wedge leg impedance on the receiver side could be represented by the impedance of the first segment in the terrain profile after the screen top and that the wedge leg impedance on the source side could be represented by the impedance of the last segment in the terrain profile before the screen top. This is a reasonable assumption for screens with almost vertical wedge faces but has been found to be less accurate if the wedge faces are horizontal and particularly if the mentioned segments are short. In the 2018-revision, it was therefore decided to improve Nord2000, so it can handle varying of impedances along the wedge legs of a screen.

In the new approach, the weighted average reflection coefficient Q_{av} is introduced based on the equivalent real reflection coefficient concept. In principle, the determination of the reflection coefficient Q_{avS} on the source side of the wedge may include the whole terrain profile from the screen top to the source whereas the determination of the reflection coefficient Q_{avR} on the receiver side may include the whole terrain profile from the screen top to the receiver. In many cases however, depending on the terrain geometry the considered range of the terrain profile shall be reduced around the screen top based on Fresnel-zone considerations and may even involve only one terrain segment on each side of the screen top as in earlier versions of Nord2000 when the wedge faces are close to be vertical.

In the procedure for calculation of the wedge leg reflection coefficient Q_{avR} on the receiver side of the screen in case of Nord2000 sub-model 4 for one screen with one edge, the segments between the screen top T and the receiver $\mathrm{R_G}$ are numbered in ascending order from i_1 = 1 to i_3 where i_1 is the number of the first segment after T and i_3 is the number of the last segment before $\mathrm{R_G}$. i_2 is the number of the first segment after the screen shape end point $\mathrm{W_2}$. The geometrical setup for the receiver side terrain is shown in Figure G.1. The terrain profile is the thin solid line and the dots on the line are segment end points.

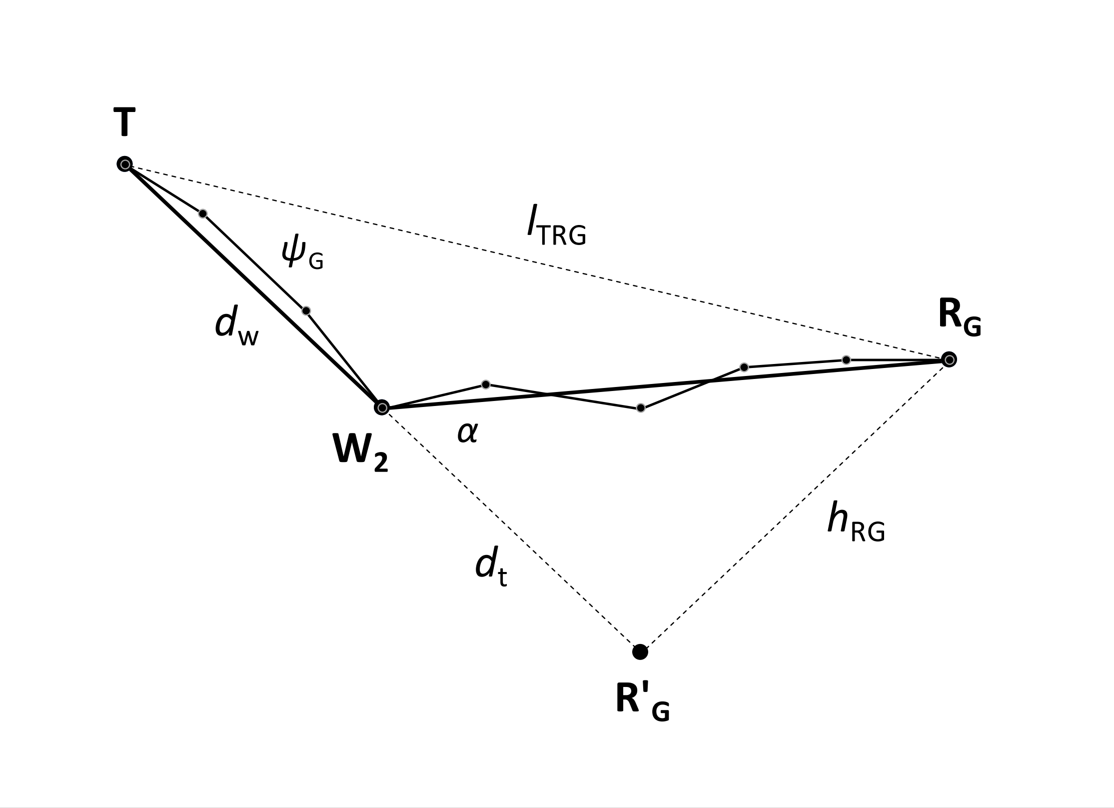

Figure G.1
Definition of geometrical setup for receiver side terrain between screen top T and receiver ground point R_G.

The calculation of Q_{avR} is based on the length l_i of each terrain segment and the impedance represented by the flow resistivity σ_i. The weight of each segment in the average are determined on basis of the scaled length l'_i. The scaling ratio depends on whether the segment is a part of the wedge shape or a part of the terrain shape.

When a segment is a part of the wedge shape between T and W_2, the calculation of the scaled length l'_i is performed as shown in Eqs. (406) to (409) where d_w is the distance from T to W_2, l_w is the sum of segment lengths and r_w is the scaling ratio.

$$d_w = |TW_2| = Length(x_T, z_T, x_{W2}, z_{W2}) \quad \textbf{(406)}$$

$$l_w = \sum_{i=i_1}^{i_2-1} l_i \quad \textbf{(407)}$$

$$r_w = \frac{d_w}{l_w} \quad \textbf{(408)}$$

$$l'_i = r_w l_i \quad for\ i = [i_1, .., i_2 - 1] \tag{409}$$

When a segment is a part of the terrain shape between W_2 and R_G, the calculation of the scaled length l'_i is performed as shown in Eqs. (410) to (413) where d_t is the distance from W_2 to R_G, l_t is the sum of segment lengths and r_t is the scaling ratio.

$$d_t = \begin{cases} 0 & \alpha \geq \pi/2 \\ |W_2 R_G| cos(\alpha) & 0 < \alpha < \pi/2 \\ |W_2 R_G| & \alpha \leq 0 \end{cases} \tag{410}$$

$$l_t = \sum_{i=i_2}^{i_3} l_i \tag{411}$$

$$r_t = \frac{d_t}{l_t} \tag{412}$$

$$l'_i = r_t l_i \quad for\ i = [i_2, .., i_3] \tag{413}$$

The scaled lengths l'i are used create an impedance profile which can be considered a kind of mapping of the segments onto the receiver side elongated wedge surface (defined as T to R'_G in Figure G.1). The impedance profile has a format as shown in Table G.1. First column is the terrain profile segment number, second column the distance from the screen top T to the end of the mapped segment measured along the elongated wedge surface, third column the ground flow resistivity, and fourth column the scaled length.

Segment index no.	End of segment from T	Ground flow resistivity	Scaled length
1	d_1	σ_1	l'_1
i	d_i	σ_i	l'_i
...	...	...	...
i_3	d_{i3}	σ_{i3}	l'_{i3}

Table G.1
Terrain impedance profile definition.

The next step is on basis of Fresnel-zone considerations to determine which part of the impedance profile is of importance when calculating the average reflection coefficient Q_{av}. Depending on the terrain geometry, it can be anything from a part of the first segment to all segments.

The size d_{FZ} of the wedge surface to consider in the method can be calculated by use of the auxiliary function CalcFZd as shown in Eq. (414) to (418). r_S is distance between the reflection point and T, r_R is distance between the reflection point and R_G, and ψ_G the grazing ground reflection angle. The constant Fλ is fraction F=1/8 of the wavelength λ corresponding to a frequency of 250 Hz and a sound speed 340 m/s. In the Nord2000 method in general, the size of a Fresnel-zone is frequency dependent. However, in the present case, that would increase the complexity of the method considerably and considering the approximate nature of the weighted average reflection coefficient concept, such an increase would hardly be justified by a similar increase in accuracy.

$$d_{FZ} = CalcFZd(r_S, r_R, \psi_G, F\lambda) \tag{414}$$

where

$$r_S = 0 \tag{415}$$

$$r_R = l_{TRG} = \begin{cases} \sqrt{(d_w + d_t)^2 + {h_{RG}}^2} & \theta \geq 0 \\ d_w + d_t & \theta < 0 \end{cases} \tag{416}$$

$$\psi_G = \begin{cases} arctan\left(\frac{h_{RG}}{d_w + d_t}\right) & h_{RG} \geq 0 \\ 0 & h_{RG} < 0 \end{cases} \tag{417}$$

$$F\lambda = 0.17 \tag{418}$$

If d_{FZ} is less that d_{i3} in Table 1 the impedance profile in the table must be truncated. This is done by finding the highest numbered row in the table where d_{FZ} is less than or equal to d_i. This row has to modified and the following rows has to be deleted. In the row to be modified, the index number is called N indicating the total number of segments, the distance to the end of the segment is changed to d_{FZ}, the flow resistivity is renamed to σ_N, and the scaled length is adjusted as shown in Table 2.

Segment index no.	**End of segment from T**	**Ground flow resistivity**	**Scaled length**
1	d_1	σ_1	l'_1
i	d_i	σ_i	l'_i
...	...	...	...
N	d_{FZ}	σ_N	$l'_N = d_{FZ}-d_{N-1}$

Table 2
Terrain impedance profile definition.

The weight of each segment to use in the calculation of Q_{avR} is determined by Eqs. (419) and (420).

$$l'_{tot} = \sum_{i=1}^{N} l'_i \quad \textbf{(419)}$$

$$w_i = \frac{l'_i}{l'_{tot}} \quad \textbf{(420)}$$

If the terrain profile consists of the wedge shape only and has no terrain shape (W_2 and R_G will be identical points), the calculations become much simpler as the scaled lengths are determined by Eqs. (406) to (409) only and the Fresnel-zone will always include the whole terrain profile.

In the Fresnel-zone concept, it is assumed that the contribution of a segment within the Fresnel-zone depends on the size of the segment alone and not on where it is placed within the Fresnel-zone. This means that it is possible to merge two or more segments with the same flow resistivity into an impedance group simply by adding the weights of the segments and thereby reduce the number of rows in the impedance weight table as shown in Table G.3. Since M≤N, this will in most cases reduce the calculation time.

Impedance group no.	**Ground flow resistivity**	**Impedance weight**
1	σ_1	w_1
j	σ_j	w_j
...	...	...
M	σ_M	w_M

Table 3
Impedance weight table.

Finally, Q_{avR} is determined on basis of the impedance weight table by Eq. (421).

$$Q_{avR}(f) = \sum_{j=1}^{M} w_j Q_e(f, \psi_G, l_{TRG}, \sigma_j) \quad \textbf{(421)}$$

The procedure described above for calculation of Q_{avR} is also used for calculation of Q_{avS} based on the source side terrain profile.

In this case, the segments between the screen top T and the source ground point S_G are again numbered in ascending order from $i_1 = 1$ to i_3 but now i_1 is the number of the last terrain segment before T and i_3 is the number of the first terrain segment after S which means that the order of the terrain impedance profile has been reversed compared to the terrain profile between S and T. i_2 is now the number of the last terrain segment before the screen shape end point W_1.

2.16.3 G.3 Determination of the Wedge Leg Ground Effects for One Screen with Two Edges (Sub-model 5)

As described in Section 5.7.4 in [1], the diffraction over one screen with two edges can be solved by considering diffraction over two wedge-shaped screens where the receiver leg of the first screen and the source leg of the second are the same (called the middle leg in [1]). The diffraction coefficient of the two-edge screen is determined by the product of the diffraction coefficient of the two screens multiplied by 0.5 as shown in Eq. (102) in [1]. The constant 0.5 compensates for the fact that the reflection in middle leg will be included twice in product.

The weighted average reflection coefficient Q_{avS} of the source side leg of the first wedge-shaped screen with top point denoted T_1 is calculated as described above in Section G.2 for the source side of the one edge screen comprising the terrain segments between the screen top T_1 and the source ground point S_G.

Likewise, the weighted average reflection coefficient Q_{avR} of the receiver side leg of the second wedge-shaped screen with top point denoted T_2 is calculated as described above in Section G.2 for the receiver side of the one edge screen comprising the terrain segments between the screen top T_2 and the receiver ground point R_G.

The weighted average reflection coefficients $Q_{avR,1}$ of receiver side leg of the first wedge-shaped screen and $Q_{avS,2}$ of source side leg of the second wedge-shaped screen are identical and is therefore denoted Q_{avM}. $Q_{avR,1}$ and $Q_{avS,2}$ becomes identical because the terrain profile between T_1 and T_2 consists of one wedge shape only and no terrain shape. In this case, the Fresnel-zone will include the whole terrain profile and the order of the terrain segments is without importance. Q_{avM} can in the first place be calculated as described above in Section G.2 for the case where the terrain profile consists of a wedge shape and no terrain shape but must be modified when the distance T_1 to T_2 is short compared to the distance S_G to R_G as described in the following

Shortly after the development of Nord2000 it was found that a finite impedance between T_1 to T_2 resulted in too much attenuation of the two-edge screen and in the 2006 revision of Nord2000 it was decided, as a temporary solution, to assume a hard surface between T_1 to T_2. This is a reasonable solution for screens that are not too wide but will underestimate the attenuation for very wide screens. However, at the time where the chosen approach was one impedance representing each wedge leg it was not possible to come up with a better solution. However, with the introduction of the weighted average reflection coefficient, it has been much easier to propose a better solution.

The modified average reflection coefficient Q'_{avM} are calculated as shown in Eqs. (422) to (426). Based on the relative screen width r_{12} defined in Eq. (424), an interpolation parameter r_{QM} is defined in Eq. (425) and used to perform a transition from Q_{avM} to Q_{hard} (equal to 1). For narrow screens ($r_{12} \leq 0.2$), $Q'_{avM} = Q_{avM}$ and for wide screens ($r_{12} \geq 0.8$), $Q'_{avM} = Q_{hard}$.

$$d_{12} = |T_1 T_2| = Length(x_{T1}, z_{T1}, x_{T2}, z_{T2}) \quad \textbf{(422)}$$

$$d_{SGRG} = |S_G R_G| = Length(x_{SG}, z_{SG}, x_{RG}, z_{RG}) \quad \textbf{(423)}$$

$$r_{12} = \frac{d_{12}}{d_{SGSR}} \quad \textbf{(424)}$$

$$r_{QM} = \begin{cases} 1 & r_{12} \leq 0.2 \\ 1 - \dfrac{r_{12} - 0.2}{0.6} & 0.2 < r_{12} < 0.8 \\ 0 & r_{12} \geq 0.8 \end{cases} \quad \textbf{(425)}$$

$$Q'_{avM} = \left(1 - r_{QM}\right) Q_{avM} + r_{QM} Q_{hard} \quad \textbf{(426)}$$

2.16.4 G.4 Determination of the Wedge Leg Ground Effects for Two Screens with One Edge (Sub-model 6)

As described in Section 5.7.3 in [1], the diffraction over two screens with one edge each can be solved by considering diffraction over two wedge-shaped screens with or without a terrain shape between them. The combined diffraction coefficient of the two screens is determined as the product of the diffraction coefficient of each screen as shown in Eqs. (97) and (98) in [1]. For screen closest to the source the diffraction angles on the receiver side of the screen are determined by replacing the receiver R by the screen top T_2 of the second screen. Likewise, for screen closest to the receiver the diffraction angles on the source side of the screen are determined by replacing the source S by the screen top T_1 of the first screen.

The weighted average reflection coefficients $Q_{avS,1}$ and $Q_{avR,1}$ of the first screen are calculated as described above in Section G.2 for the one edge screen with the exception that the receiver side is comprising terrain segments between the screen top T_1 and T_2.

Likewise, the weighted average reflection coefficients $Q_{avS,2}$ and $Q_{avR,2}$ of the second screen are calculated as described above in Section G.2 for the one edge screen with the exception that the source side is comprising terrain segments between the screen top T_2 and T_1.

Furthermore, $Q_{avR,1}$ and $Q_{avS,2}$ are modified into $Q'_{avR,1}$ and $Q'_{avS,2}$ to obtain a better transition between the two-screen case and the two-edges case when geometry is virtually the same. This has been made possible with the introduction of the weighted average reflection coefficient.

The geometrical setup for calculating $Q'_{avR,1}$ and $Q'_{avS,2}$ is shown in Figure G.2. T_1 and T_2 are the top points of the first and second screen, respectively. W_{12} is the wedge point of the first screen on the receiver side and W_{21} is the wedge point of the second screen on the source side. Δh_1 and Δh_2 are the vertical distances of the two wedge points below the line T_1T_2.

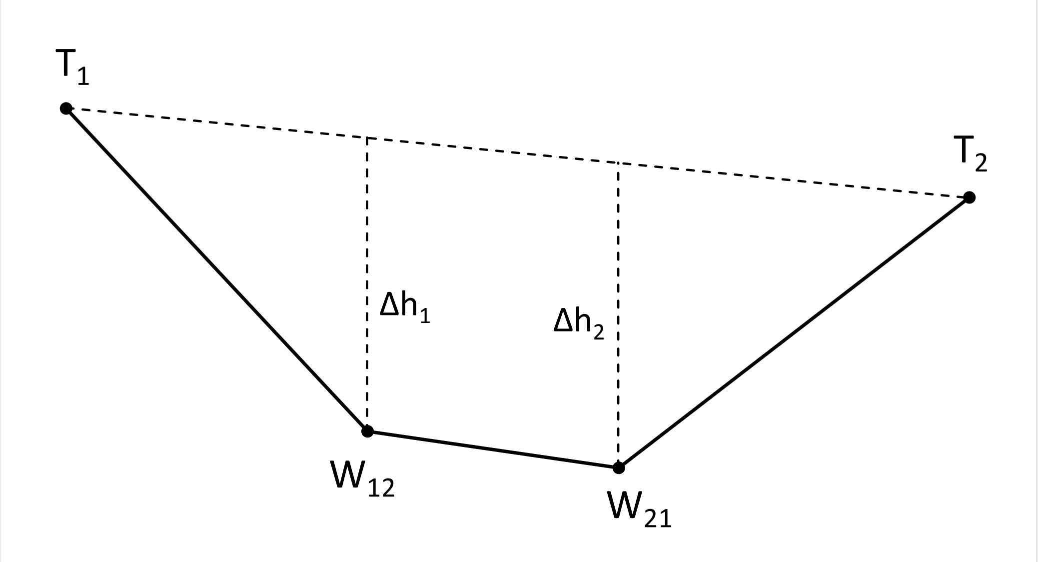

Figure G.2
Definition of geometrical setup for calculation of $Q'_{avR,1}$ and $Q'_{avS,2}$.

When determining the modification of Q_{av} between the screen tops, the first step is to calculate Δh_1 and Δh_2 using the auxiliary function *VertDist* as shown in Eqs. (427) and (428). If Δh becomes negative (W is above the line T_1T_2), Δh is set to a value of 0.

$$\Delta h_1 = -VertDist(x_{T1}, z_{T1}, x_{T2}, z_{T2}, x_{W12}, z_{W12},) \quad \textbf{(427)}$$

$$\Delta h_2 = -VertDist(x_{T1}, z_{T1}, x_{T2}, z_{T2}, x_{W21}, z_{W21},) \quad \textbf{(428)}$$

Based on Δh_1 and Δh_2, a path length difference Δl from T_1 to T_2 over W_{12} and W_{21} is determined as defined in Eqs. (429) to (433).

$$l_{T1T2} = Length(x_{T1}, 0, x_{T2}, 0) \quad \textbf{(429)}$$

$$l_{T1W12} = Length(x_{T1}, 0, x_{W12}, \Delta h_1) \quad \textbf{(430)}$$

$$l_{W12W21} = Length(x_{W12}, \Delta h_1, x_{W21}, \Delta h_2) \quad \textbf{(431)}$$

$$l_{W21T2} = Length(x_{W21}, \Delta h_2, x_{T2}, 0) \quad \textbf{(432)}$$

$$\Delta l = l_{T1W12} + l_{W12W21} + l_{W21T2} - l_{T1T2} \quad \textbf{(433)}$$

Then, the distance normalized path length distance $\Delta l'$ is determined by Eq. (434). The reason that the normalized $\Delta l'$ is used, is to obtain that the same shape of $T_1W_{12}W_{21}T_2$ (with the same angles) provides the same transition coefficient independent of distance.

$$\Delta l' = \frac{\Delta l}{l_{T1T2}} \tag{434}$$

Finally, the transition coefficient r_{QMtr} shall be calculated by Eq. (435) where $\Delta l'_0$ is a constant that defines at above which value of $\Delta l'$, $Q'_{avR,1} = Q_{avR,1}$ and $Q'_{avS,2} = Q_{avS,2}$.

$$r_{QMtr} = \begin{cases} 1 - \dfrac{\Delta l'}{\Delta l'_0} & \Delta l' < \Delta l'_0 \\ 0 & \Delta l' \geq \Delta l'_0 \end{cases} \tag{435}$$

The constant $\Delta l'_0$ equal to 0.003820 has been determined by Eq. (436) at an angle $\theta_0 = 5^\circ$. The equation shows the value of $\Delta l'_0$ when $W_{12} = W_{21}$ and placed halfway between T_1 and T_2 at the angle θ_0 with the line T_1T_2. The implies that the transition to the two-edge screen will take place within a magnitude of shape angles of around 5°.

$$\Delta l'_0 = \sqrt{1 + \tan^2(\theta_0)} - 1 \tag{436}$$

As shown in Eq. (437), the interpolation parameter needed to obtain a transition from $Q_{avR,1}$ and $Q_{avS,2}$ to Q_{hard} shall also include the two-edge screen interpolation parameter r_{QM} from Eq. (425) here denoted $r_{QM,2edge}$.

$$r_{QM} = r_{QMtr} r_{QM,2edge} \tag{437}$$

Based on the interpolation parameter r_{QM}, the weighted average reflection coefficient $Q_{avR,1}$, and Q_{hard} (= 1), the modified reflection coefficient $Q'_{avR,1}$ for the receiver side of the first screen can be calculated as shown in Eq. (438). The reason for the constant 0.5 in the second term of the equation is that the diffraction coefficient of the two-edge screen model is determined by the product of the diffraction coefficient of the two screens multiplied by 0.5 to compensate for fact the reflection in middle leg will be included twice in product whereas the combined diffraction coefficient of the two-screen model is determined as the product of the diffraction coefficients of each screen. Likewise, the modified reflection coefficient $Q'_{avS,2}$ for the source side of the second screen can be calculated by Eq. (439).

$$Q'_{avR,1} = \left(1 - r_{QM}\right) Q_{avR,1} + 0.5\, r_{QM} Q_{hard} \tag{438}$$

$$Q'_{avS,2} = \left(1 - r_{QM}\right) Q_{avS,2} + 0.5\, r_{QM} Q_{hard} \tag{439}$$

2.16.5 G.5 Determination of the Wedge Leg Ground Effects by the Energy Reflection Coefficient

As described in the introduction of Annex G, a simplified approach can optionally be used when it is only possible to define the reflective properties of the wedge leg surfaces by a simple energy reflection coefficient $\rho_E(f)$ or absorption coefficient $\alpha(f)$. In that case, the equivalent real reflection coefficient $Q_e(f)$ is determined by Eq. (440).

$$Q_e(f) = \sqrt{\rho_E(f)} = \sqrt{1 - \alpha(f)} \tag{440}$$

3. References

[1] B. Plovsing, *Proposal for Nordtest Method: Nord2000 – Prediction of Outdoor Sound Propagation*, DELTA Acoustics, Report AV 1106/07 (revised), Hørsholm, January 2014.