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Refining the CNOSSOS-EU calculation method for environmental noise

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ABSTRACT

By the first of January 2019 all member states are required to transpose the CNOSSOS-EU calculation method (EU directive 2015/996) in their legislation. In preparation a study was conducted in 2017 to evaluate the new calculation method. Part if this evaluation was to see if the method could also be used to replace the Dutch national method. In this study we found errors within the method that, if implemented, would lead to implausible results. The results of this study were presented to the EU commission and the Noise Regulatory Committee. As a result an EU working group, chaired by the Netherlands, was established to study and propose amendments to the method. This EU working group has found numerous issues. Some issues are about unclear text, which may lead to different interpretations of the method. Other issues are more fundamental. They are clear errors in the method. One serious example is the problem that occurs with multiple diffractions in favourable conditions.

For almost all the issues a solution is drafted. A report is finalized where these issues and proposed solutions are discussed. In this paper we will present issues, solutions and the remaining issue.

Keywords: Noise, Cnossos
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

CNOSSOS-EU [1] is the new calculation method for rail, road and industrial noise used to produce noise maps according to the Environmental Noise Directive [2] (END). This calculation method had to be transposed in legislation for all the member states before January 1 2019. The purpose of introducing an unified calculation method is that noise maps, produced according to the END, can be compared between member states. The Netherlands prefers to have a single calculation method for all purposes. Which means NOSSOS-EU was seen as a replacement for the current national methods for road, rail and industrial noise. The national methods are currently used for detailed calculations for planning and licensing. That means noise requirements are tested with calculations. These requirements are to be met in situations when a new dwelling is built, permitting for industry, changes in infrastructure etc. That means that the

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requirements are more strict compared to noise mapping. In 2017 RIVM examined if CNOSSOS-EU meets the requirements to use as a national method. We concluded CNOSSOS-EU does not meet these requirements. We also concluded there are even issues that imply the method, in its current form, is unsuited for noise mapping. These conclusions were presented to the Noire Regulatory Committee (NRC) of the EU at the end of 2017.

In 2018 an EU working group, chaired by the Netherlands and mandated by the NRC, was formed to study refinement of CNOSSOS-EU. The group identified all the issues, then categorized these issues and finally proposed solution on how the method can be amended so that these issues are addressed. In this paper we first describe the types of issues found, after some important amendments are discussed. There was one issue for which no solution is drafted yet. This issue will be discussed separately.

2. ISSUES IN CNOSSOS-EU

2.1 Finding and categorizing issues

At a first meeting of the working group a total of 60 issues were raised. Not all of these issues can be addressed by a modification of the legal text of CNOSSOS-EU. There are issues for example that should be addressed in a (modelling) guideline instead of the legal text. Only those points that could be addressed in the legal text of CNOSSOS-EU were taken under consideration. All other points were mentioned in the final report[3]. We do recommend that a guidance document will be drafted. An example as guidance is a method to determine the percentage of favourable conditions. In that case no differences due to different approaches by member states will occur.

The issues taken under consideration were dived into three categories. The first was an issue concerning unclear text, the second was an issue concerning an error in the method and the third was an issue where the method could be improved. In the next sections a few examples are presented. In the final report [3] a complete overview is presented.

2.2 Modified heights with ground attenuation

In some cases, the actual text is not clear; the result is that different people can interpret the method in different ways. These different interpretations can lead to different results. This became clear when a software implementation of CNOSSOS-EU gave different results compared to the implementation published on the EU website.

In CNOSSOS-EU the source and receiver height are modified when calculating ground attenuation in favourable conditions: "*In the equation of $A_{ground,H}$, the heights z_s and z_{sr} are replaced by $z_s + \delta z_s + \delta z_t$ and $z_r + \delta z_r + \delta z_t$ respectively*"[4]. There was some discussion if these modified heights should also be used when determining the lower bound of the ground attenuation as shown in equation 1.

$$A_{ground,F,min} = \begin{cases} -3\left(1-\overline{G_m}\right) & if\ d_p \leq 30(z_s+z_r) \\ -3\left(1-\overline{G_m}\right) * \left(1+2\left(1-\dfrac{30(z_s+z_r)}{d_p}\right)\right) & otherwise \end{cases} \quad (1)$$

Is some cases the difference is significant:

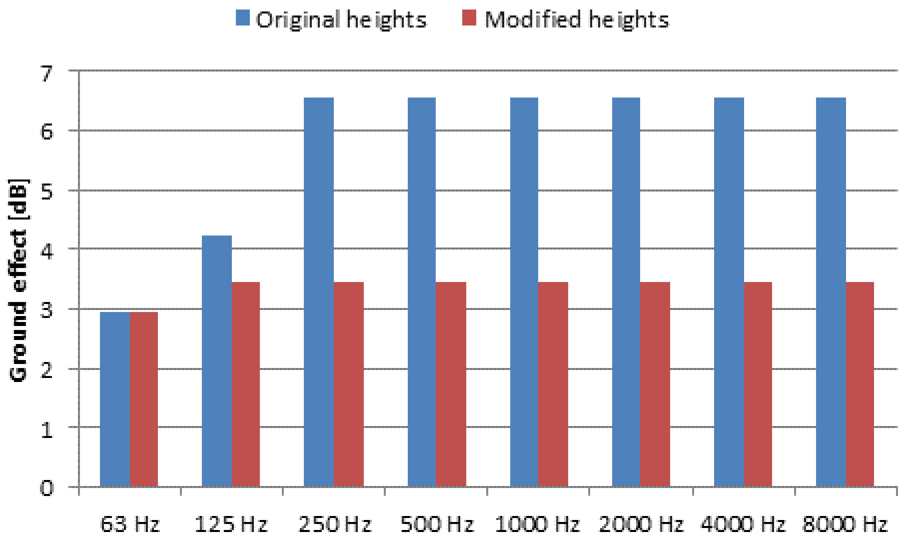

Figure 1: Difference between ground effect in case of use of either modified or unmodified heights in case of reflective Surface, source height 0.05 meter, receiver 4 meters and distance 300 meters

In communication with different experts, it became clear that no modified heights should be used in the formula for the lower bound of ground attenuation. The CNOSSOS-EU code on the EU website contains an error. The working group has decided to propose a simple amendment to clarify this point.

2.3 Source/receiver below the mean plane

A second example is that heights of source and receiver are determined is relation to the mean ground plane. If this equivalent height becomes negative (the point lies below the mean ground plane) a null height is retained. It should be clear that in the calculation of diffraction these null heights are not be used. The path length differences stays valid without changing the coordinates of the source or the receiver.

Other issues were minor, but relevant. Examples were missing units (km/h of m/s) or obvious incorrect headers in tables.

2.4 Rayleigh Criterion

In the CNOSSOS-EU calculation method there is a difference between a model that might include diffraction and one that does not. The CNOSSOS-EU text states that:

"As a general rule, the diffraction shall be studied at the top of each obstacle located on the propagation path. If the path passes 'high enough' over the diffraction edge, A_{dif} = 0 can be set and a direct view calculated, in particular by evaluating A_{ground}.

In practice, for each frequency band centre frequency, the path difference δ is compared with the quantity $-\lambda / 20$. If an obstacle does not produce diffraction, this for instance being determined according to Rayleigh's criterion, there is no need to calculate A_{dif} for the frequency band considered. In other words, A_{dif} = 0 in this case. Otherwise, A_{dif} is calculated as described in the remainder of this part. This rule applies *in both homogeneous and favourable conditions, for both single and multiple diffraction.*"

The text suggests that if either the Rayleigh criterion is fulfilled or if the path passes high enough over the diffraction edge the situation should be considered as if there is no diffraction point. One of the issues is that the determination of the Rayleigh criterion is not defined. This is relevant because ground attenuation calculated with or without a diffraction point is different, even if there is no diffraction. An example of the result of possible approaches is shown below:

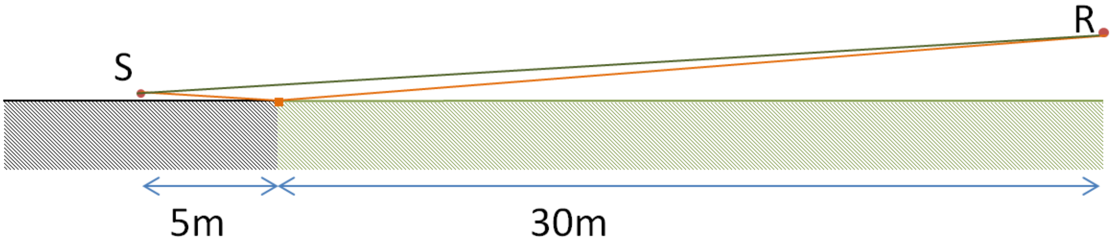

Figure 2: Example of a relatively flat model with source (S) height 0.05 meter, receiver (R) height 4 meters and a slight barrier of 0.1 meter height. The left 5 meters is a reflective surface and the right thirty meters is an absorbing Surface.

In the cases above we first consider the case presented in CNOSSOS-EU, the path difference δ is larger than the quantity $-\lambda / 20$. In table 1 these values are compared for each octave band.

Table 1: Comparison of path length difference and the quantity $-\lambda / 20$ for the example shown in figure 2.

Frequency	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
δ	-0.031	-0.031	-0.031	-0.031	-0.031	-0.031	-0.031	-0.031
$-\lambda/20$	-0.270	-0.136	-0.068	-0.034	-0.017	-0.009	-0.004	-0.002
$\delta > -\lambda/20$	Yes	Yes	Yes	Yes	No	No	No	No

Form table 1 it is clear that with such al low source a diffraction edge will always occur no matter how small the artefact in a model. The difference is attenuation is significant. In the case only a ground model with no diffraction is considered the ground attenuation is determined by A_{ground}. When a (potential) diffracting edge (O) is considered the ground attenuation is taken into account in the diffraction term $\Delta_{dif(S.R)} + \Delta_{ground(S,O)} + \Delta_{ground(O_n,R)}$. The most important difference is the separation of a ground attenuation between source and diffraction edge and between diffraction edge and receiver.

Table 2: Attenuation in the case example 1 is considered as flat or with diffraction

Frequency	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Flat	-2.26	-2.26	-2.26	-2.26	-2.26	-2.26	-2.26	-2.26
Diffracted	1.46	1.13	0.38	-1.75	-3.00	-2.58	-3.00	-3.00
Difference	3.72	3.39	2.64	0.51	-0.74	-0.32	-.074	-0.74

Table 2 shows that a minute elevation in terrain can lead significant different calculation results. So a second criterion is necessary: the Rayleigh Criterion. In this case we sum the (negative) path length difference as calculate above with the (positive) path length difference (δ^*) calculated with a mirror receiver and mirror source but with the same diffracting edge. If the sun is larger than $\lambda / 4$ the Rayleigh criterion is fulfilled and the ground is not considered to be flat. As in table 1 we show these results.

Table 3: Test of Rayleigh criterion for the example shown in figure 2.

Frequency	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
$\delta + \delta^*$	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
$\lambda /4$	1.349	0.680	0.034	0.017	0.009	0.004	0.002	0.0011
Rayleigh fulfilled?	No	No	No	No	No	No	Yes	Yes

In table 3 we show that the Rayleigh criterion triggers at high frequencies while in table 1 the low frequencies were triggered. One might conclude that only if both the Rayleigh criterion is fulfilled and the comparison with $-\lambda$ / 20 diffraction should be taken into account. Another example however shows that this may not be the case.

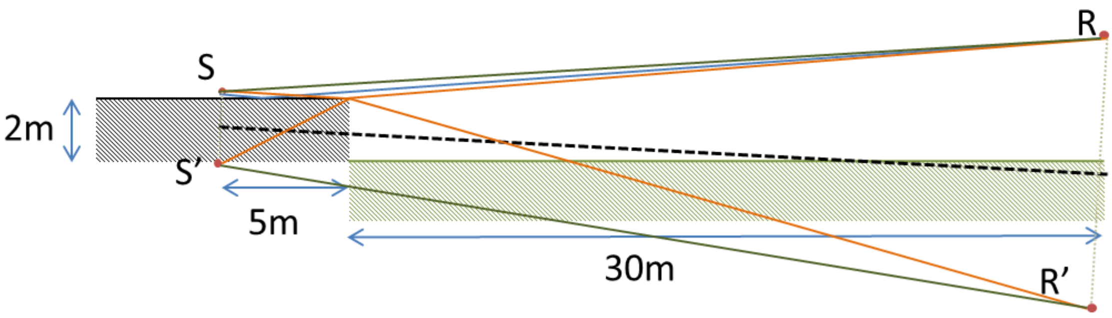

Figure 3: Example[5] of an elevated road (bridge) with source (S) height 0.05 meter, receiver (R)height 4 meters. The left 5 meters is a reflective surface and the right thirty meters is an absorbing Surface. The dashed line is the mean plane. Also shown are image source and receiver relative to the mean plan.

In this case results of the test of the criteria are:

Table 4: Test of criteria for the example shown in figure 3.

Frequency	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
$\delta > -\lambda/20$	Yes	Yes	Yes	Yes	No	No	No	No
Rayleigh fulfilled?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

In this case there is a similar condition to see if a sound ray goes high enough over a diffraction point as in the previous example. The Rayleigh criterion however shows a much larger difference.

Two possibilities were proposed within the working group. The first possibility is: Both $\delta > -\lambda/20$ and the Rayleigh criterion need to be fulfilled for diffraction to possibly occur. The second possibility is: Only the Rayleigh criterion is used. As mentioned before the main difference occurs due to the way the ground attenuation is taken into account.

2.5 Multiple diffractions in favourable conditions

One of the main point that got attention was an error that can occur in case of more than one diffraction point in favourable conditions. Because of this error more screens or diffraction points can result in less attenuation and higher noise levels. The cause for the error is that straight lines are used to determine diffraction points while the propagation follows curved lines. The effect is shown in the figure 4.

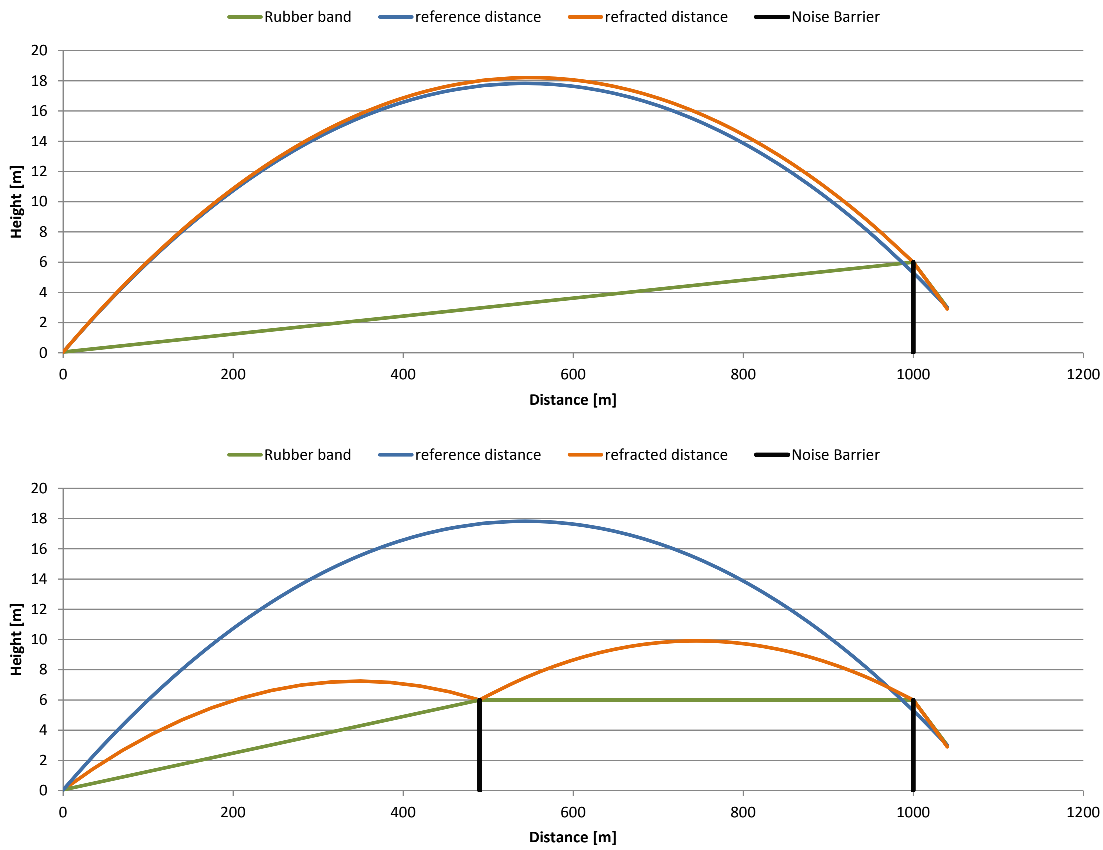

Figure 4: Calculation of the path difference of the diffracted path and the direct path

In figure 4 we show that with one diffraction point the direct path is shorter than the diffracted path, hence an attenuation is calculated. In the case where there is a second diffraction point the diffracted path is (much) shorter compared to the direct path, there is no attenuation. This problem could be fixed by either curving the ground and using straight lines to determine path length differences or to use curved rays to determining which diffraction points should be used. PE[6] calculations showed no clear preference so it was chosen to use the curved ray approach.

2.6 Ground attenuation

The ground attenuation method used in CNOSSOS-EU is completely different form the one used in ISO9613-2[7], especially at distances above 200 meters. An example is shown below. On the left are ground attenuations for CNOSSOS-EU in favourable conditions and ISO9613-2. On the right is the total ground attenuation for CNOSSOS-EU with 30% favourable and 70% homogeneous conditions and for ISO9613-2 with the meteorological correction included.

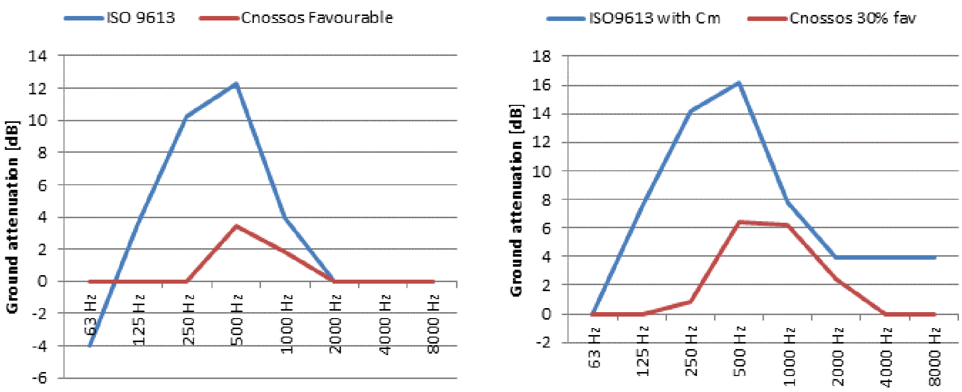

Figure 5: Different ground attenuations for CNOSSOS-EU and ISO9613-2 considering absorbing ground, distance 200 meters, source height 0.5 meters and receiver height 4 meters

Figure 5 shows with favourable conditions the ground attenuation of ISO is much higher compared to CNOSSOS-EU. If a mix of favourable and homogeneous conditions is taken into account the difference with the ISO method is still very high. Most notably at 250 and 500 Hz with differences of 13.4 and 9.7 dB respectively. A consequence is that, if the same source power is used the noise levels in CNOSSOS-EU will be much higher than one is used to using ISO9613-2. For railroad noise we calculated up to 5 dB higher noise levels and correspondingly larger contour levels.

A second point concerning the ground attenuation is that in CNOSSOS-EU source and receiver are not interchangeable. This is due to the fact that the ground type below the source is relevant until distances of 30 times the source+receiver height as illustrated by formula 2.5.14 from Annex II:

$$\begin{cases} G_{path}\dfrac{d_p}{30(z_s+z_r)} + G_s\left(1-\dfrac{d_p}{30(z_s+z_r)}\right) & if\ d_p \le 30(z_s+z_r) \\ G_{path} & otherwise \end{cases} \qquad (2)$$

Where G_{path} is the average ground value between source and receiver and G_s is the ground value at the source.

An example of the effect of interchanging source and receiver is shown below.

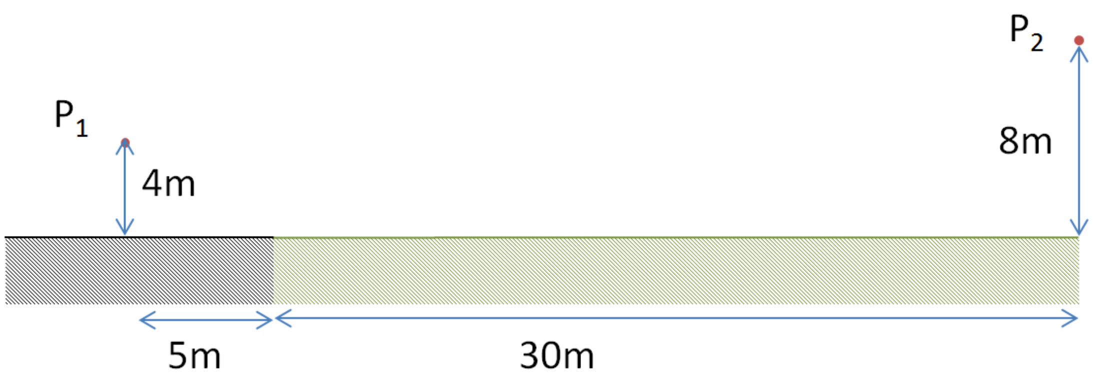

Figure 6: Schematic view of two potential models.

One can define 2 cases: First where P_1 is the source and P_2 the receiver, the second where P_2 is the source and P_1 the receiver. In the first case the ground attenuation is -2.8dB, in the second case it is 0 dB. This difference of 2.8 dB is not according to the fundamental principal that source and receiver may be reciprocating. The potential error is most clear with higher sources, the main reason is that with low sources the first reflection takes place near the source. In that case the ground type below the source is more important. For industrial noise this will often not be the case. A significant error in calculated level may occur. Originally, the calculation method was designed for rail and road noise in which the approximation looks acceptable. The expansion to cover industrial noise seems premature.

In our opinion the difference of the ground attenuation and between CNOSSOS-EU and ISO9613-2 should be explained. The current position is we expect that the noise exposed area that will be reported shall be much higher compared to the previous rounds of noise mapping

4. CONCLUSIONS

For road, rail and industrial noise the current Annex II of EU directive 2015/996 contains numerous errors or is unclear on a number of points. An EU working group has addressed the issues presented possible solutions. There is one remaining issue, the ground attenuation, where there is such a big difference between CNOSSOS-EU and other common models that it is unsure if this ground attenuation can be correct. Also the ground attenuation model is fundamentally flawed for high sources. More research will be needed to possibly develop an improved ground attenuation model that can be used with CNOSSOS-EU.

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6. REFERENCES

1. S Kephalopoulos, M. Paviotti, F. Anfosso-Lédée, *"Common Noise Assessment Methods in Europe (CNOSSOS-EU)"*, JRC Reference report 2012

2. *DIRECTIVE 2002/49/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL relating to the assessment and management of environmental noise*, 25 June 2002

3. A. Kok et.al., *"Amendments to CNOSSOS-EU"*, RIVM report 2019-0023, forthcoming 2019

4. *COMMISSION DIRECTIVE (EU) 2015/996 Establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council*, 19 May 2015

5. D. van Maercke, *Private communication,* 2018

6. E.M. Salomons, F.J.M. van der Eerden, A.R. Eisses, *"Implementation of Cnossos in NL Analysis of various issues"*, 2018

7. ISO 9613-2:1996, *"Acoustics -- Attenuation of sound during propagation outdoors -- Part 2: General method of calculation"*, 1996