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Quality assurance methods demonstrated with the calculation of sound propagation with ISO 9613-2 and with CNOSSOS-EU

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ABSTRACT

Many methods have been developed and where even implemented in legally binding rules how sound propagation shall be calculated to support the minimization of environmental noise. Especially in the case of such legal requirements it is necessary to ensure that the agreed algorithms are applied in the same way by all experts independent from the software tool they use. With the series of the International Standard ISO 17534 we created a framework to ensure this necessary precision. One of the main pillar of the strategy is to clarify all ambiguous definitions and to close the gaps that will cause different results if programmed by different software developers. With standard ISO 9613-2 examples are shown where even existing definitions had to be modified. It can be stated that all calculation methods have their shortcomings that can only be detected if the method is realized in software and then practically applied. The same is true with the harmonized European calculation method – here abbreviated as “CNOSSOS-EU”. Examples are shown where it was necessary to modify and clarify some definitions before it was possible to create test cases to check the correct implementation of the method.
With this work on about 30 Test Cases for ISO 9613-2 and for CNOSSOS-EU we learned a lot about the optimal strategy if a new method shall be implemented or an existing method shall be improved. Some recommendations for future projects of that type will be given.

Keywords: Sound propagation, Prediction, Quality assurance

1. INTRODUCTION

In the past two decades a lot of effort was made to improve the accuracy of calculation models of the “engineering type” for sound propagation. With all these engineering models like ISO 9613-2:1996 [1], Harmonoise Engineering Model [2], or NMPB:2008 [3] the sound waves swapping over the ground with all the objects above like vegetation, buildings and walls are replaced by some geometrically exact defined ray paths. Many approximations are necessary to ensure an acceptable accuracy – in this context accuracy means the agreement between calculated and measured sound pressure levels – but to keep the methods simple enough to support the necessary precision – this means that different experts applying the method shall get the same results for a given problem. These two aspects are concurrent and we will never succeed to find the universal and final calculation method. A severe problem is that the different physical phenomena like ground influence, attenuation by vegetation, screening and meteorological influences are not independent but are treated in the calculations as if they were. At the end, all these developments are a balancing act between the detailed mathematical description of obviously relevant physical phenomena, on the one hand, and the practical application in complex environments of the real world with many unknown interdependencies and therefore necessary approximations, on the other hand. An example is the inclusion of meteorology in engineering calculation models: While the calculation method ISO 9613-2 is based on a single meteorological condition favorable to propagation it was a large step driven by the European activities to include vertical temperature profiles and wind speeds in the Harmonoise Engineering Model [4]. Taking into account the above mentioned balance it was finally decided to use the calculation method NMPB:2008 as the Common European calculation method for noise mapping under the acronym CNOSSOS-EU. This acronym is in the following applied as shortcut for the legally binding text describing the calculation of sound propagation in the European directive 2015/996/EU

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With the International Standard ISO 17534-1 [6] measures to ensure the necessary correctness if these methods are implemented in software where defined and decided. Part 1 of this Standard defines the general frame, Part 2 is a sort of library for Test Cases and for each calculation method one of the following parts published as Technical Reports contains the method specific measures.

The main core of such a method specific documentation for quality assurance is a set of additional specifications that are necessary to clarify open issues and – in some cases – to modify existing definitions from the official publication that have proven to be faulty and further a set of test cases with detailed step by step and final results.

The first step made in 2015 was the Quality Assurance of the calculation method ISO 9613-2:1996. The method is applied worldwide and it was necessary to correct some algorithms and procedures that were obviously not designed to be implemented with nowadays available computer-power. These last four years the main software-platforms applied ISO 9613-2 in connection with these “Additional Recommendations” of ISO/TR 17534-3 [7] and it can be stated that this strategy improved the communication between all experts engaged in software development and implementation.

Based on this positive experience the next step was to start a similar project related to the Quality Assurance of CNOSSOS-EU:2015. The method is by far more complicated than ISO 9613-2 and many additional specifications and clarifications were necessary to ensure the unambiguous interpretation of the official text in the European Directive. During the work on this planned Part 4 of ISO 17534 in Working Group 56 of ISO TC43 SC1 some implausible results were detected in the calculation of multiple diffraction with favorable propagation conditions. It was a lucky coincidence that the work for Quality Assurance was not finished that time so that an improvement could be developed – published in [8] - and integrated as an additional specification. A special Test Case was constructed to check the correct implementation of this new strategy in different software applications.

2. QUALITY ASSURANCE WITH ISO 17534 – A POWERFUL FRAMEWORK FOR SOFTWARE-IMPLEMENTED CALCULATION METHODS

One of the main targets of quality assurance in the implementation of calculation methods in software is to ensure identical or with an acceptable frame of uncertainty comparable results. Consultants or other noise experts applying one of the commercially available software-packages must rely on the correct implementation even if they are not able to check this in each individual case themselves. Checking the correctness of an implementation is easier with clear and consistent calculation procedures, but on the other side there is a tendency to include more and more acoustically relevant phenomena and thus to make calculation strategies more complex.

The drafts of ISO 17534 – series try to solve this balancing act by introducing adequate measures. The structure of this series is shown in figure 1 – it takes into account that there is one group of basic and generally prevailing measures and another group of method specific actions.

The core standard is ISO 17534-1. It describes 6 blocks of actions that set up requirements for calculation methods that shall be implementable quality assured and for the software package as a platform where even more calculation methods can be offered alternatively.

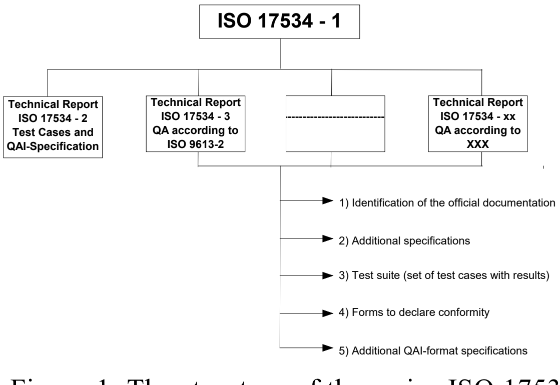

Figure 1: The structure of the series ISO 17534

For each calculation method that shall be included in that framework of quality assurance an own Technical Report is foreseen. As a first example the Technical Report ISO 17534–3 was drafted for the calculation method ISO 9613 -2. It is required for a method specific Technical report to identify clearly and unambiguously the official documentation, even if the relevant algorithms and strategies are spread over more publications. Secondly the Technical Report may contain "Additional recommendations" being a decided supplement if the method according to the official documentation is not complete or ambiguous in some aspects. Such additional specifications may also be necessary if open and undefined issues require all software developers to find an own solution – in such cases the working group decides for a common solution as long as there is not a responsible standardization group taking this action. Summing up the Additional recommendations are preliminary advices to ensure the necessary precision (same results with the same test case) and finally to make a calculation method fit to be quality-assured despite these undefined parts. A further important part of the method specific Technical Report is a suite of test cases with step by step and final results. With these results an interval with acceptable deviations to rank the calculated values as correct is given. It shall only be mentioned that these test cases shall be as simple as possible to facilitate the necessary checks and only as complex as necessary to prove the correct calculation of the algorithms under test. There is also a form to be applied by the software developer to declare conformity. Finally the data exchange by a common format may need some method specific supplements – these are also included in the method specific Technical Report.

3. DIFFRACTED SOUND – THE APPROACH WITH ISO/TR 17534-3

3.1 Clarifications to improve the software application of ISO 9613-2

A typical example for necessary improvements of an existing standardized procedure in the frame of quality assurance with the framework of ISO 17534 is the calculation of screening with ISO 9613-2. Due to this standard the barrier attenuation D_z is a function of z, where z is the difference between the pathlengths of diffracted and direct sound. It is calculated in case of a single barrier with

$$z = [(d_{ss} + d_{sr})^2 + a^2]^{1/2} - d \qquad (1)$$

and in case of double diffraction with

$$z = [(d_{ss} + d_{sr} + e)^2 + a^2]^{1/2} - d \qquad (2)$$

where d_{ss} is the distance from the source to the first diffraction edge, d_{sr} the distance from the second diffraction edge to the receiver, a the component distance parallel to the barrier edge between source and receiver and e the distance between the two diffraction edges in the case of double diffraction.

With more than two barriers it is recommended to apply the last equation choosing the two most effective barriers.

With software implementations of ISO 9613-2 many problems arose due to ambiguities of these definitions. Equation (1) can be derived from the principle that the shortest path source-barrier edge-receiver is relevant, but equation (2) makes only sense if the two edges of a double barrier are parallel. With software applications with many objects like buildings and barriers this condition is an extremely seldom case and therefore it makes no sense to implement it.

This problem was solved by defining a more general procedure to find the propagation paths that are regarded as representative as it is shown in Figure 2 for the propagation from a source S (red) to a receiver R (green). One path crossing the objects blocking the direct line S-R is the shortest "ribbon-band-line" in a vertical plane containing S and R and up to two further paths are the shortest convex polygon lines in a lateral plane that includes also S and R and is perpendicular to the first plane.

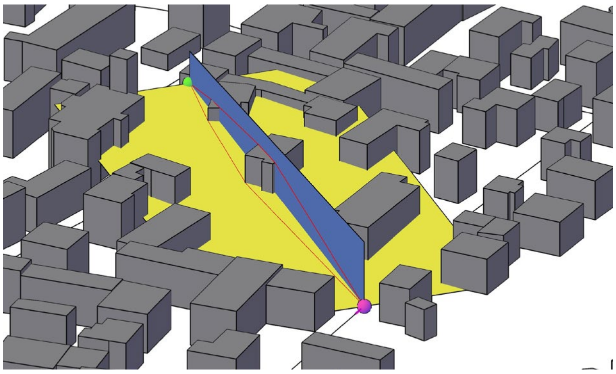

Figure 2: Construction of the shortest paths from source to receiver in a vertical plane (blue) and a lateral plane (yellow)

3.2 Test cases to check the correct implementation

In ISO/TR 17534-3 a set of 19 Test Cases is included with about 68 tables with step-by-step and final results. The Test Cases are constructed to cover all the important algorithms and to check their correct implementation following the principle: as simple as possible and only as complicated as necessary. An example is the Test case shown in Figure 3 that was constructed to check the calculation of diffraction over top and laterally for a short barrier where the properties of the ground varies along the propagation path.

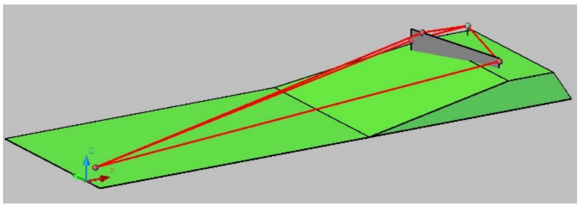

Figure 3: Short barrier with varying heights and acoustic properties of the ground

Another example where more objects like buildings are blocking the line of sight is shown with Figure 4. The aim of this Test Case is to include the construction of paths representing the laterally diffracted sound in more complicated scenarios.

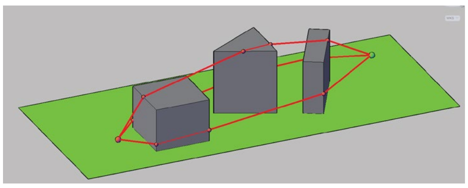

Figure 4: Three building blocking the direct line of sight between source and receiver

A further important part of this framework of quality assurance are the conformity sheets where the developer of the software product under test declares that all the relevant parts of the official documentation and the additional specifications are correctly included and that the results for all test cases can be reproduced in the defined intervals.

4. QUALITY ASSURANCE FOR THE IMPLEMENTATION OF CNOSSOS-EU

4.1 Problems encountered and proposed solution

The calculation method for sound propagation CNOSSOS-EU is based on the French method NMPB 2008. As described in the introduction above, the calculation method showed some strange and not plausible results when it was applied in Noise-Mapping-Projects. From experts in the Netherlands it was reported that screening by objects like buildings and embankments may be strongly underestimated in special cases with favorable propagation conditions and therefore noise levels in urban areas can be overestimated by 5 to 10 dB

The reason for these not plausible results is the method how the diffracted ray paths are constructed. Figure 5 – scenario 1 with source S (height 3 m), receiver R (height 5 m) in a distance of roughly 1 km and barrier B with a height of 10 m - shows in the upper part the well-known ribbon-band-construction related to homogeneous propagation conditions to find the difference between the pathlengths of diffracted and direct sound and from that the resulting barrier attenuation.

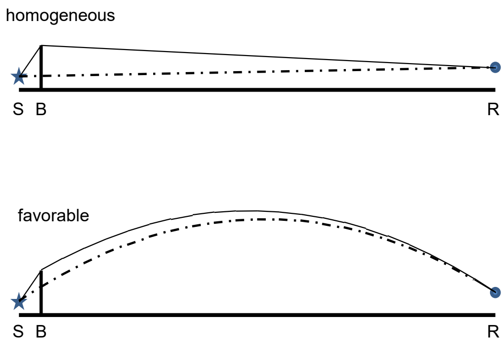

Figure 5: The direct ray path (dash-dot) and the diffracted ray over top of the barrier for both propagation conditions as defined with CNOSSOS-EU:2015 (scenario 1)

With favorable propagation conditions the straight lines from homogeneous conditions are replaced by arcs with a radius R_{curv} that is a function of the distance between source and receiver.

The attenuations due to diffraction calculated with CNOSSOS-EU:2015 are shown in the columns with header "scenario 1" in Table 1.The attenuations are smaller with favorable compared to homogeneous conditions in agreement with expectation.

Table 1: Attenuation due to diffraction for all scenarios and for both propagation conditions

Frequency Hz	Attenuation due to pure diffraction Δ_{diff} dB calculated with									
	CNOSSOS-EU:2015						proposed modification			
	scenario 1		scenario 2		scenario 3		scenario 2		scenario 3	
	hom	fav	hom	fav	hom	fav	hom	fav	hom	fav
63	6.9	6.5	6.3	0.0	9.6	3.8	6.3	3.7	9.6	6.5
125	8.2	7.8	7.5	0.0	11.8	2.6	7.5	2.4	11.8	7.8
250	10.1	9.5	9.2	0.0	14.3	0.0	9.2	0.0	14.3	9.5
500	12.5	11.7	11.3	0.0	17.1	0.0	11.3	0.0	17.1	11.7
1000	15.1	14.3	13.8	0.0	20.0	0.0	13.8	0.0	20.0	14.3
2000	17.9	17.0	16.5	0.0	22.9	0.0	16.5	0.0	22.9	17.0
4000	20.8	19.9	19.4	0.0	25.9	0.0	19.4	0.0	25.9	19.9
8000	23.8	22.9	22.3	0.0	28.9	0.0	22.3	0.0	28.9	22.9

With scenario 2 shown in Figure 6 the barriers B1 – B6 with heights between 6 m and 12 m are inserted. The detailed coordinates are not reported here – they can be taken from the original publication [8].

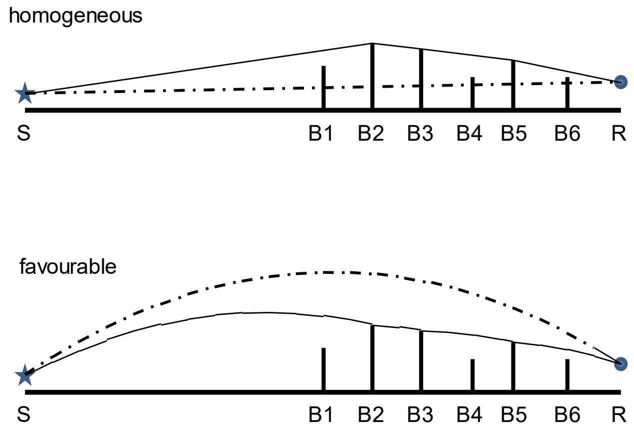

Figure 6: Scenario 2 with barriers B1 – B6 and relevant ray paths in agreement with the definition in CNOSSOS-EU:2015

The upper part in figure 5 (homogeneous conditions) defines on basis of the ribbon-band-construction the relevant diffraction edges B2, B3 and B5 and in the lower part (favorable conditions) these same edges are connected with arcs. As it is shown in the columns with the header "scenario 2" in Table 1, no attenuation due to diffraction is calculated for this case and the curved direct ray is assumed to propagate undisturbed by the barriers.

Now a scenario 3 is created combining scenarios 1 and 2 as it is shown in Figure 7.

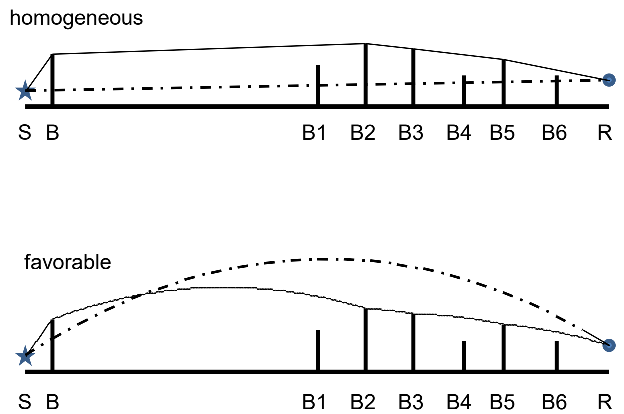

Figure 7: Scenario 3 with all barriers of scenario 1 and scenario 2 combined

The attenuations with this scenario 3 calculated for favorable conditions with CNOSSOS-EU:2015 are with exception of the lowest two frequency bands 0 dB, as it is shown in Table 1. This means that the high attenuations of barrier B in scenario 1 are reduced to 0 dB if the barriers B1 – B6 are inserted additionally – a result not plausible and not in agreement with expectation even taking into account the approximation of the sound wave by geometrically defined ray-paths.

The reason for this unexpected result is the strategy to regard the same barrier edges as relevant under favorable conditions as they were found for homogeneous conditions applying the ribbon-band-method. The proposed and tested solution is to construct the path for favorable conditions completely analogous as for homogeneous conditions as a convex envelope but with arcs instead of straight lines. Connecting source S with all barrier edges and the receiver R the first diffracting edge is defined by the maximal gradient of the arc at source S – if this gradient is the largest for the arc from source S to the receiver R the curved direct ray is not blocked. In case a barrier edge is found that way this is taken as the starting point for the next arc and this is repeated till the receiver R is reached.

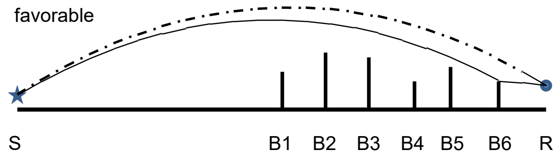

Figure 8: Ray paths for scenario 2 (favorable) calculated with the proposed method

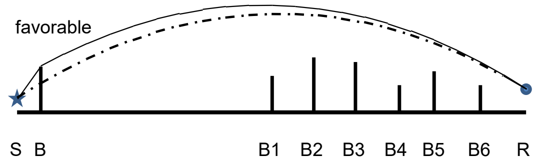

Figure 9: Ray paths for scenario 3 (favorable) calculated with the proposed method

Applying this proposed solution we get for scenario 2 under favorable conditions the ray path shown in Figure 8 and for scenario 3 the ray path shown in Figure 9. The attenuations calculated on the basis of the proposed strategy shown in the last 4 columns of Table 4 are now in agreement with our expectation taking into account the behavior of sound waves in a downward refracting atmosphere.

4.2 Test cases to check the correct implementation of CNOSSOS-EU

The above described modification is only one aspect that had to be taken into account in the preparation of a draft for a new ISO/TR 17534-4 related to Quality assurance of CNOSSOS-EU. Some other additional specifications were necessary to make the official text unambiguous and precise for the implementation in different software platforms.

The set of 19 Test Cases developed with ISO/TR 17534-3 (related to ISO 9613-2) was extended and now this complete set contains 28 cases.

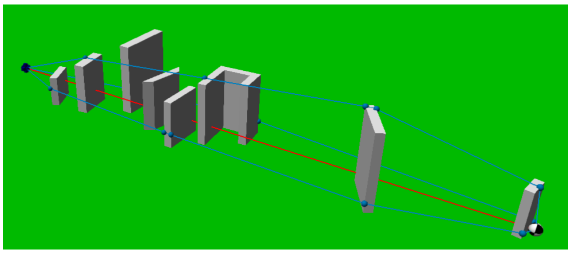

Figure 10: Test Case with 8 buildings and calculation-rays for homogeneous conditions

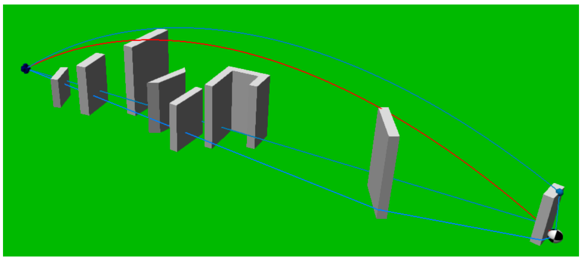

Figure 11: Test Case with 8 buildings and calculation-rays for favourable conditions

Figures 10 and 11 show the last Test Case No. 28 constructed so that the “correct” calculation of the ray paths can be checked – correct in the sense that the above explained solution is assumed to be integrated in a revised version of CNOSSOS-EU.

At the time this paper is written a working draft of the planned ISO/TR 17534-4 is just finalized by ISO TC43 SC1 WG 56. Therefore all the above is only a report from ongoing work and far from being decided and accepted. But it was the aim to give an impression of the many activities that are necessary to reach the target – a calculation method unambiguously defined and described that can be implemented in different software platforms and used by different experts even in different countries with the intended high precision.

5. FINAL REMARKS

The authors experience from these and other cases where it was tried to integrate more physics in the algorithmic scheme of calculation methods that shall be applied even in legally controlled areas to prevent people from unwanted and not acceptable effects is a clear dominance of precision over the aspects of accuracy. We should accept that these methods applied are – and must be – relatively crude approximations. In the case of environmental noise we want to predict the sound caused by complex sources like industrial facilities, propagating in an atmosphere with timely varying temperature profiles roughly simulated by the applied algorithms and over vegetated and/or built up and often complex shaped ground surfaces. We must accept that the methods of geometrical acoustics applied need a thorough balancing of all the effects influencing the accuracy of the final result. What we need is a robust and transparent engineering method where thousands of consultants applying them have a chance to make plausibility controls and to check the reason for unexpected results.

ACKNOWLEDGEMENTS

I acknowledge the work of the colleges in Netherlands – especially the acousticians in RIVM – for their critical work with CNOSSOS-EU where they detected the problems of the diffraction calculation with favorable propagation conditions. It was the basis for my own analysis and gave me and my colleges the possibility to contribute the solution described above to the working group on CNOSSOS-EU installed by DG ENVIRONMENT. We hope that it will soon be integrated in a revised Annex II of the Directive.

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