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NOISE CONTROL FOR QUALITY OF LIFE

Measures to increase accuracy and precision of software-based noise prediction

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ABSTRACT

Following some similar national activities around quality assurance of software for noise calculations, an International Standardization activity was started with WG 56 of ISO/TC43/SC 1. The aim of this standard is to clarify the requirements that must be fulfilled by the software products and by the calculation methods to be implemented. Goal of this strategy is a complete transparency of the implemented calculation routines to keep them open for discussion between experts, to give software developers the possibility to check the correct implementation and to enable software users to verify this. Important steps discussed in this frame are additional specifications to adapt the methods better to the needs of software realization and test cases to support the correct implementation and verification. With the example of the calculation method ISO 9613-2 some important steps are demonstrated and discussed.

Keywords: Standards, Noise, Calculation, Quality

1. INTRODUCTION

The prediction of noise levels is an extremely important activity in our engineered world. If road or railway systems, industrial facilities or even air route systems in the vicinity of airports are planned or shall be modified, the pre-calculation of probable noise impacts caused by these developments is the only method to check if legal requirements can be fulfilled. Nearly all calculations with the aim to predict noise levels are undertaken by applying software tools. Software products with more than one alternatively selectable calculation method implemented are software platforms, often organizing many other important jobs and operations like the user interfacing, the data input and output facilities, the tools to inspect and modify the input data and last not least the tools to present and analyze the final results.

Competition between the software developing companies is a powerful engine to drive progress for user-friendly man-machine interfaces and other features that facilitate the daily work of acousticians and other groups dealing with noise issues. This can easily be proven by comparing these aspects between such software platforms and "stand-alone-solutions" where legal requirements make it compulsory to apply a defined software package.

This advantage of highly developed software platforms requires some actions for quality assurance to ensure a high accuracy and precision in noise predictions independent of the product applied. Accuracy in the frame of quality assurance is a qualification of the correct calculation in agreement with the official documentation of the method – the agreement with measurements is not touched. High precision means that the spread of results obtained with different software products is small.

The necessary measures comprise some features of the software product itself but also agreement of the developers about calculation details that are not part of the documented calculation method. A set of test cases with documented step by step results must be developed for each calculation method to verify the correct implementation.

In the following some of such measures based on more than 20 years of experience with such software techniques are discussed and presented. It is planned to agree on a set of such or similar measures in the frame of an International Standard [1] to support software developers and software users.

2. SOFTWARE-FEATURES SUPPORTING QUALITY ASSURANCE

As mentioned above, the priorities for features and user-support may be different with different software products. But some of these features are so important for many decisions and for the quality of the final result that it is strongly recommended to integrate them in all software products claiming high quality.

Only two examples shall be mentioned. The first is the possibility to show graphically all ray-paths taken into account in a calculation of the level at defined receiver points.

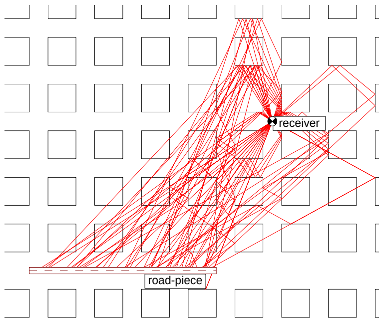


Figure 1 – The ray paths taken into account to calculate the noise level from a piece of road at the receiver

Without such a quick control of the calculations performed it is not possible to check what sound contributions have been included in the final result.

Another feature is the determination of the uncertainty of noise maps caused by acceleration settings like reduced search radii or the neglect of lower level contributions. The German Standard DIN 45687 [2] describes the technique: if the calculation area is defined, a selected number of receiver points is distributed statistically inside this area taking into account some requirements about minimum distance to sources and reflecting objects, the levels are calculated once with a reference setting (no acceleration technique) and once with these settings intended for the calculation of the noise map, the so called project related or alternative setting. Then the level differences are analyzed and the 0.1 and 0.9 percentiles define the interval of deviations caused by this setting. It is extremely helpful if all these steps are triggered by a single command or mouse-click before the time consuming calculation of the noise map is started.

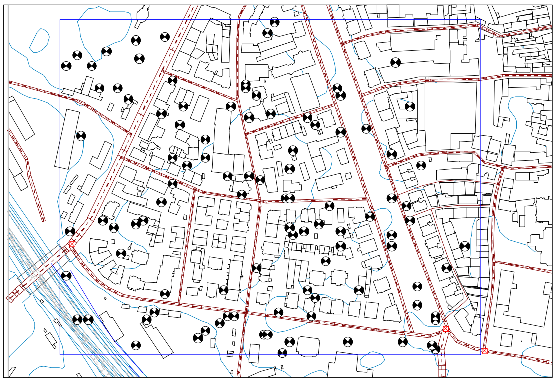


Figure 2 – Receiver points distributed automatically according to standardized requirements

The result of such an analysis comprising generally about 100 or more receivers is presented as an interval specifying the uncertainty of results due to the deviation of the software configuration from reference settings.

Statistical analysis (example):

$$q_{0,1} = -2{,}0 \text{ dB}$$
$$q_{0,9} = 0{,}0 \text{ dB}$$

There are some more elements extremely important for software users and thus even regarded as compulsory to be part of high-quality software products. An example is a common data format and interface [3] to exchange complete projects between software platforms supporting it.

3. EXAMPLES OF ADDITIONAL SPECIFICATIONS

The most effective and successful approaches to calculate sound propagation in large and complex environments are those based on rays or particle trajectories. But it is necessary to have in mind that the replacement of a wave field swashing over such complex scenarios by a finite – and due to calculation times relatively small – number of well defined ray paths is an approximation and needs a careful weighting of the importance of these paths taken into account. If one knows about the approximation and what has been neglected it is always possible to construct a test case where the method fails completely and produces large errors. The skill is not to avoid such errors, but to find principles of approximations where the probability of errors is minimized taking into account the most frequently occurring scenarios.

It is obvious that the spread of results with different software implementations of the same calculation method can only be reduced if these approximations are identical. In future it should be a demand for all authors of calculation methods to take all these problems into account if the method shall be applied in such complex environments. Some examples of such recommendations are given in the following.

The general method to decide about the ray paths that shall be taken into account from source to receiver is shown in figure 3 for one and in figure 4 for many objects blocking the direct propagation path.

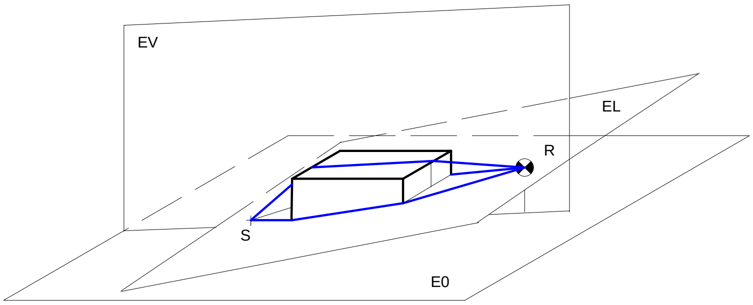


Figure 3 – The two planes EV and EL to check possible propagation paths between source and receiver

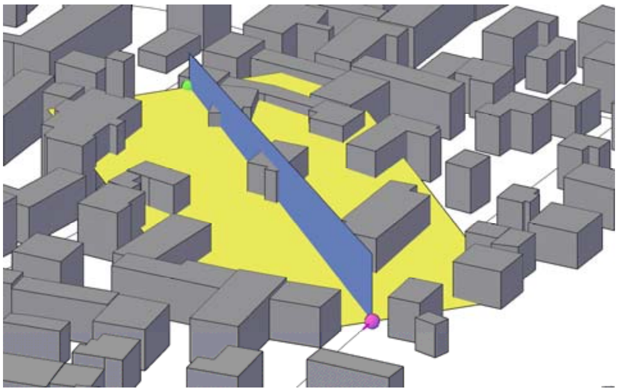


Figure 4 – The planes EV and EL with source (red) and receiver (green) in complex environment

The plane EV contains source and receiver and is perpendicular to the reference plane E0 (x-y-plane). The plane EL also contains source and receiver and is perpendicular to plane EV.

It shall be mentioned that the strategy taking these two planes is well proven to be an acceptable – if not the best possible – compromise. It takes into account that most environments with buildings and other objects are vertically relative to the reference plane and that slope angles of the terrain are negligible or small in practical cases.

What ray paths are considered and how the sound contributions are calculated and summed up depends on the calculation standard. The following additional specifications are recommended if ISO 9613-2 [4] shall be applied.

Recommended additional specification for the quality assured application of ISO 9613-2:

Generally 3 contributing ray paths shall be taken into account – one over top in plane EV and two lateral diffracted rays in plane EL.

The ray path in plane EV connects source and receiver like a ribbon enveloping the diffracting edges as shown in figure 5.

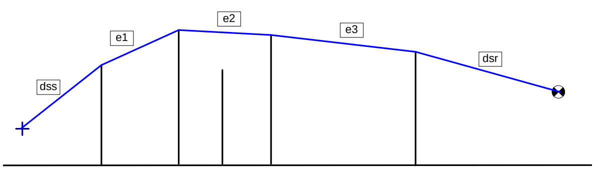


Figure 5 – The calculation ray in plane EV

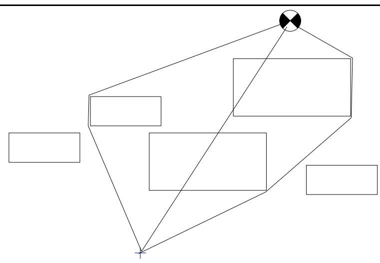


Figure 6 The two calculation rays in plane EL

The length of the polygon-segments between the first and the last diffracting edge is the parameter e needed in equation (15) of ISO 9613-2.

The two ray paths in plane EL left and right from plane EV are shown in figure 6. The condition for the selection of the relevant polygon points for lateral diffraction in plane E_L is the bending to the left at the right side in each point and the bending to the right at the left side in each point thus forming the shortest possible convex envelope.

The path length difference z of each of these three contributions is the difference in length of the ribbon and the straight direct line from source to receiver.

This more general specification is necessary because the parameter a in equations (16) and (17) – the component distance parallel to the barrier edge – is only applicable and meaningful with one single or with more parallel diffraction edges. To get a continuous and consistent solution not producing spatially fluctuating levels in noise maps it is by far more precise to apply generally the described ribbon method with planes EV and EH.

It may be discussed – but at the end it should be decided – if the calculation of z with equation (16) and (17) shall be applied in the very special case if one single barrier with cantilever is cut by the vertical plane EV, because the maximal two diffracting edges of such a barrier with cantilever are generally parallel.

If the attenuation of a barrier with cantilever shall be calculated and the source is located below the tilted part, the path determined in the cross section of plane EV may be considerably longer than the shortest possible path.

This shortest path between the point source – may be a piece of road – and the receiver can be constructed as shown in figures 7a – 7d. Figure 7 b shows two artificial planes – the first contains the upper left diffraction edge and the source and the second is defined by the bend-edge and the receiver point. These artificial planes with source and receiver are now folded up into the plane of the tilted part as it is shown in figure 7c – here the shortest possible connection of source and receiver is a straight line and the points where the ray crosses the diffracting edges can be determined. The shortest possible ray path is then the polygon line connecting the original source with these points and the original receiver according to figure 7d. This line is not a straight line in ground projection and it may be considerably shorter than the line constructed with plane EV (figure 8).

With equations (16) and (17) of ISO 9613-2 the length of this shortest possible ray path is taken into account to determine z. But each further object with a diffracting edge not parallel to the cantilever destroys this simple method and these equations cannot be applied.

To avoid these errors caused by the deviation of the lengths of these ray paths the following specification is recommended:

Generally the cut of the plane EV vertical on the reference plane x-y and containing source and receiver is applied to construct the ribbon-type polygon from source to receiver. If diffraction edges from only one single barrier with cantilever contribute to the shape of this polygon, the path length difference z is determined by equations (16) or (17) of ISO 9613-2. Otherwise the length of the ribbon-type polygon in plane EV is applied to determine z.

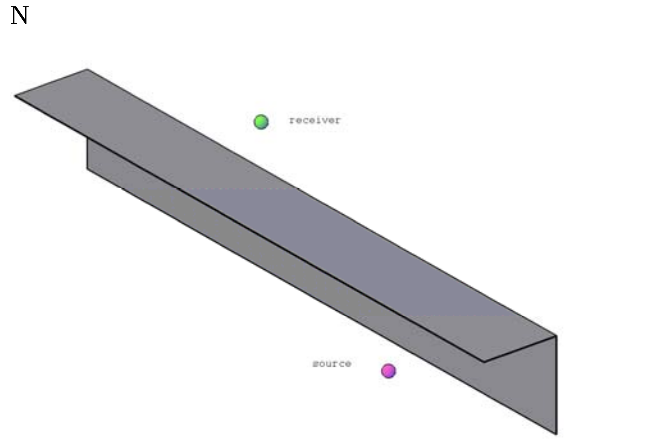


Figure 7a – Barrier with cantilever and source under the tilted part

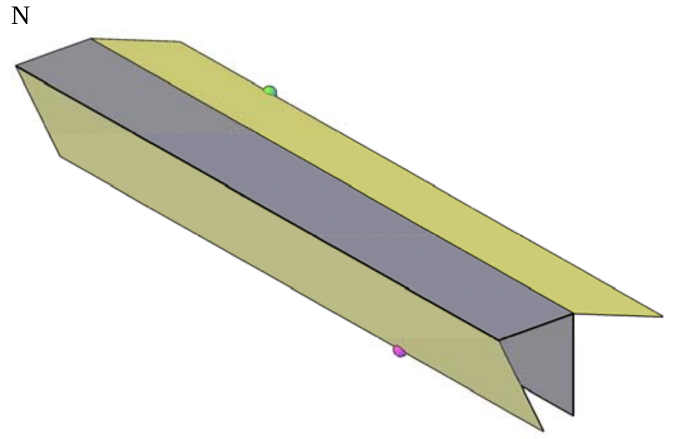
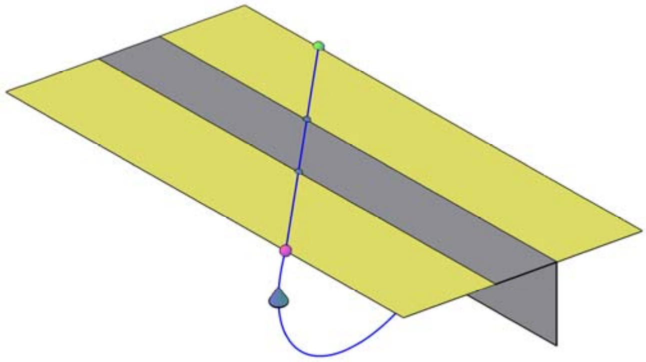
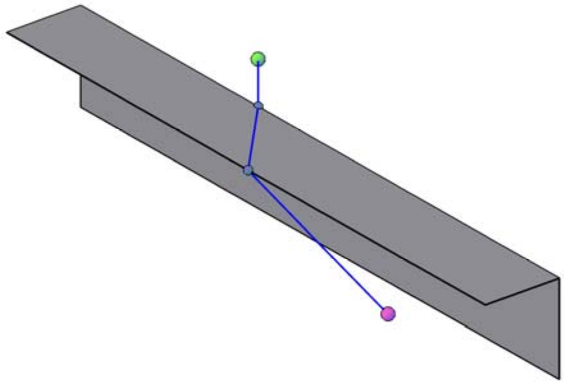


Figure 7b – Artificial planes (yellow) containing source or receiver and fixed at the next diffraction edge

 Figure 7c – Artificial planes folded up to get the shortest possible ray path as straight line	 Figure 7d – The shortest possible ray path

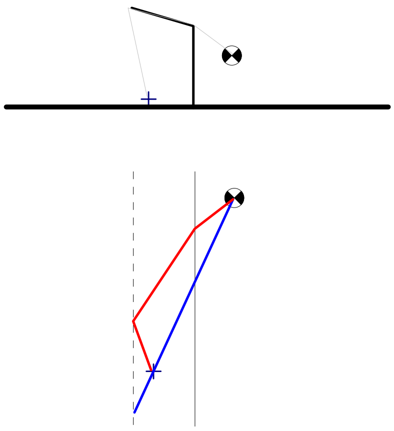


Figure 8 – Ray paths over a tilted screen. Blue – ray construction with vertical plane EV, red – shortest ray path

A further necessary specification is the limitation of the barrier attenuation – in ISO 9613-2 the relevant barrier attenuation shall be limited to 20 dB with one and to 25 dB with more diffraction edges. It has proven to be advantageous to apply this limitation only to the diffraction over top in plane EV – the lateral extension can be very large and in that cases the contribution from these edges far away should not be relevant.

4. TEST CASES IN THE FRAME OF QUALITY ASSURANCE

4.1 Test cases with published step by step results

The correct implementation of a calculation method in a software platform can best be checked if test cases with step by step results are published. In future it should be the responsibility of the authors of a method to support such a framework of test cases where the main equations and procedures are covered. The test cases shall be as simple as possible and only as complex as necessary for the intended checks.

The following is an example for ISO 9613-2, where the diffraction calculation according to the above described additional specifications is checked.

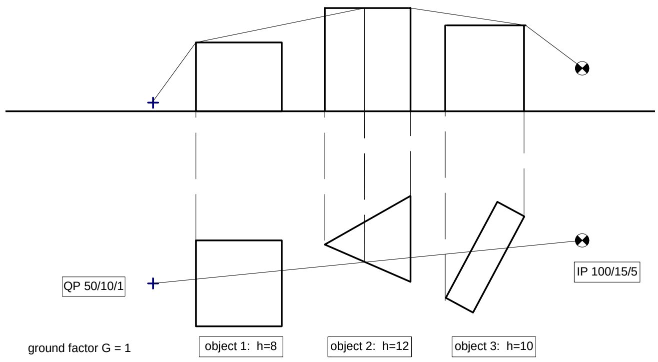


Figure 9 – Example of a test case to check the diffraction calculation with more objects

The scenario is characterized by soft ground (G = 1), air-conditions 20°C and 70% r. h. and a sound power level of the source of 93 dB (linear) in all 8 octave-bands from 63 Hz up to 8000 Hz. The limits of 20/25 dB for the maximal barrier attenuation are only applied for diffraction over the top edges – no limitation for lateral diffraction.

Table 1 is a documentation of the complete step by step results.

Table 1 – Step by step results with interval limits for “correct” results

Frequency Hz	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	
LW dB	**93**	**93**	**93**	**93**	**93**	**93**	**93**	**93**	
α-atm(20°,70%)	0.1	0.3	1.1	2.8	5.0	9.0	22.9	76.6	
Aatm	0.01	0.02	0.06	0.14	0.25	0.45	1.15	3.86	
a', b', c', d' for s		1.82	6.48	7.10	2.79				
Agr_s	-1.50	0.32	4.98	5.60	1.29	0.00	0.00	0.00	
a', b', c', d' for r		3.41	2.07	1.50	1.50				
Agr_r	-1.50	1.91	0.57	0.00	0.00	0.00	0.00	0.00	
Agr_m	13.64	17.80	21.38	22.92	22.92	22.92	22.92	22.92	
Agr	-3.00	2.22	5.56	5.60	1.29	0.00	0.00	0.00	
C3 - top	1.76	2.42	2.82	2.95	2.99	3.00	3.00	3.00	
Dz - top	15.71	19.88	23.46	25.00	25.00	25.00	25.00	25.00	
Abar - top	15.71	17.66	17.90	19.40	23.71	25.00	25.00	25.00	
C3 - left	1.73	2.40	2.80	2.95	2.99	3.00	3.00	3.00	
Dz - left	13.84	17.90	21.48	24.65	27.70	30.71	33.72	36.73	
Abar - left	13.84	17.90	21.48	24.65	27.70	30.71	33.72	36.73	
C3 - right	1.64	2.31	2.77	2.94	2.98	3.00	3.00	3.00	
Dz - right	14.70	18.89	22.59	25.82	28.88	31.90	34.91	37.92	
Abar - right	14.70	18.89	22.59	25.82	28.88	31.90	34.91	37.92	
Abar	9.91	13.35	15.40	17.56	21.40	23.32	24.08	24.51	
Adiv	45.05	45.05	45.05	45.05	45.05	45.05	45.05	45.05	**Total**
L dB	41.03	32.37	26.94	24.64	25.01	24.18	22.72	19.57	42.05
A-weighting	-26.2	-16.1	-8.6	-3.2	0.0	1.2	1.0	-1.1	
LA dB	14.83	16.27	18.34	21.44	25.01	25.38	23.72	18.47	30.96
Upper Limit	**14.8**	**16.3**	**18.3**	**21.4**	**25.0**	**25.4**	**23.7**	**18.5**	**31.0**
Lower Limit	**14.8**	**16.3**	**18.3**	**21.4**	**25.0**	**25.4**	**23.7**	**18.5**	**31.0**

Such test cases are an invaluable help for software developers and software users – from the authors point of view a calculation method cannot be implemented quality assured if it is not possible to verify the correct interpretation of all steps of the official documentation. It is planned to develop and publish such detailed test cases with clear result intervals for the calculation methods that shall be implemented quality assured according to [1] in method-specific Technical Reports.

4.2 Round robin tests with complex test scenarios

The target of all such activities is to reduce the spread of results obtained with identical input data but with different software products. The precision of a method in practical applications is better if this resulting spread can be kept smaller. This is especially of interest if the results of calculations, even if undertaken with different software products, shall be applied with legal issues.

It is obvious that test cases with step by step results cannot be undertaken for realistic larger scenarios such as built up areas or even cities (see figure 2).

To cover even this problem – the spread of results or the precision of the method applied with large scenarios – the following steps are recommended.

Step 1: Organization of a round robin test with minimum three software developing companies.

As these are generally competitors it is absolutely necessary to agree on the procedure that all decisions need consensus. The participants agree on a neutral person as a team-leader with an acceptance of 100%.

Step 2: Undertaking the round robin test.

The dataset with receiver points, the relevant calculation method to be applied and the configuration settings according to the intended test-design are distributed by the team-leader. The participants calculate the levels at the receiver points and return these results in a spread-sheet table to the team-leader.

Step 3: Statistical analysis of results

The team-leader organizes all results together in one table – one line for each receiver point and one column for each participant addressed anonymous as participant A,B…and so on. In one column the arithmetic mean of the results of all participants and in a further column the maximal absolute difference of the individual results and the mean value is presented. From the sorted list of these maximal absolute differences the quantil $q_{0.9}$ according to DIN 45 687 F.4 is derived as the final quantification for the precision of the method taking into account different software implementations. The participants can identify their own results, the results of the others anonymous and the mean values and maximal absolute deviations from the mean value.

An example data-set for a city with an area of about 290 km² and with 400 statistically distributed receiver points to be applied for such checks is published with [5]. The results presented there are related to the calculation method RLS-90 [6], but the dataset can be applied for any other calculation method implemented to check the grade of precision with such a round robin test.

This described process can even be applied to improve a method, if not defined issues in the documentation or other shortcomings of the calculation method are the reason for not acceptable dispersion of results. This needs to analyze the largest deviations, to agree on additional specifications and to repeat the round robin test in even more iterative steps.

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[4] ISO 9613-2, Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation

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[6] RLS-90:1990, Guidelines for road traffic noise abatement; corrected reprint (german language) February 1992