A COMPARISON OF ISO 9613-2 AND ADVANCED CALCULATION METHODS USING OLIVE TREE LAB-TERRAIN, AN OUTDOOR SOUND PROPAGATION SOFTWARE APPLICATION: PREDICTIONS VERSUS EXPERIMENTAL RESULTS

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1 INTRODUCTION

Although ISO 9613-2[1] was published in 1996, many people in the industry still rely on this method to carry out their work. P.E. Mediterranean Acoustics Research & Development (PEMARD) conducted a poll at the end of 2011 on LinkedIn, asking members of the Institute of Acoustics (IOA) and The Acoustical Society of America (ASA), which outdoor sound propagation method or model they use more often. The response from both organizations was very limited but very illuminating. Out of twenty seven responses from the IOA and eleven from the ASA those who still prefer the ISO method correspond to 74% and 63% respectively. The other alternatives in the poll were Nord 2000, Harmonoise, Concawe and others, from which only Nord 2000 and Harmonoise could be described as advanced models. These advanced models have already been implemented in commercial user friendly software application packages. A valid question is then, why do practitioners still prefer ISO 9613-2.

The need for standardisation cannot be disputed since standards are set up by organisations to provide the methodology by which independent investigations ought to derive the same conclusions. The down side of this need is that sometimes standardisation is being perceived by society as a dogma, beyond which one should not investigate matters deeper. Moreover, often enough the engineering community tends to neglect the science (or lack of it) underlying standardised methods and just follows prescriptions.

At the same time, standardised methods provide algorithms which can be turned into software code. Software developers are always looking for ready-made algorithms with great market potential. Furthermore, the responsibility of the accuracy of these methods do not lie with the developers but with the standards organisations. This is not the case with algorithms based on pure scientific research where the full responsibility lies with those who turn it into software applications.

As software developers PEMARD, had to make a choice whether to follow the more convenient course of developing tools based on prescribed methods, or applications based on scientific findings. There are pros and cons to both approaches; standards usually provide a simpler mathematical code, with fast and approximate results. On the other hand, state of the art science provides complicated mathematical computation, slower and yet more accurate results than standardised methods. Olive Tree Lab – Terrain, PEMARD's outdoor sound propagation software application, applies the latter without compromising accuracy and precision. However, under the pressure of the market, PEMARD will be including the ISO method along with its advanced methods.

The main body of the report presents comparison of results among published measured data, the ISO 9613-2 method and the advanced calculation methods implemented in OTL – Terrain. Prior to that, a short description is given about the methods used in OTL – Terrain and ISO. A section is dedicated to discussing the results and another on the implementation of advanced methods.

2 OLIVE TREE LAB–TERRAIN, THEORETICAL BACKGROUND

OTL – Terrain is a software application which simulates and predicts outdoor sound propagation using advanced calculation methods. It utilizes sound ray modelling which solves Helmholtz's sound wave equation and thus accounts for sound diffraction to any order, the phenomenon of the bending of sound around objects. Furthermore, it accounts for sound wave reflection from finite size surfaces of finite impedance using Fresnel Zones and spherical wave reflection coefficient concepts, respectively. OTL – Terrain does away with the concept of sound absorption coefficient and deals instead with flow resistivity. Furthermore, it takes into account geometrical spreading, atmospheric absorption, and atmospheric turbulence. These embedded features allow the study of wave interference phenomena in resolutions down to single frequencies.

The software application calculation engine is based on the work of Salomons[2] who applies a ray model using analytical solutions. Spherical wave diffraction coefficients are given by Hadden and Pierce[3]. Spherical wave reflection coefficients are based on the work of Chessel and Embleton[4], while ground impedance is based on the Delany and Basley model[5]. Finite size reflectors Fresnel zones contribution is taken into account by applying the work of Clay[6]. The atmospheric turbulence model used is based on Harmonise[7]. The Sound Path Explorer (SPE), a module used by OTL – Terrain, is an in-house developed algorithm to detect valid diffraction and reflection sound paths from source to receiver in a proper 3D environment. Sound path detection is based on the image source method and the Geometrical Theory of Diffraction according to Keller[8].

From the above it is evident that OTL - Terrain is based on principles of physics with an effort to avoid as much as possible empirical or approximate methods. To this end, other than the ISO 9613-2 method to be introduced due to clients demand, the only other empirical model is the Delany and Basley model.

The limitations of OTL - Terrain are for the time being, the following: Noise sources do not include directivity properties, diffraction calculations apply to infinite edges, results are only shown in the frequency domain and atmospheric refraction is not yet included. The product is still young and it is a matter of time to overcome the aforementioned limitations.

3 ISO 9613-2 BACKGROUND

It is well known that this standard is an empirical standard[9] therefore one should offer criticism bearing this fact in mind. At the time of its preparation and publication, there were only few dedicated acoustical software applications and most of the potential users of such software were "computer-phobic" since program user interface was not as convenient as it is today. Furthermore, even though theoretical work on this subject was available at the time[9], it does not lend itself for calculations in a spreadsheet format, like ISO 9613-2 does. It can therefore be said that there were good grounds to apply simpler empirical methods at the time. There are however, many limitations in this method.

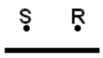
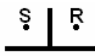
According to the authors' opinion, the weakest part in implementing this method is its' vagueness. The user decides whether vertical diffraction paths are important or not, the user has to decide on material reflection properties, the user interprets and decides how to use foliage, site and housing attenuation factors. This flexibility should in essence remove any grounds from the method to be considered as a standard. Other weaknesses of the method are that uneven grounds cannot be properly modelled, calculations are carried out on 1/1 octave centre frequencies and sound energy calculations remove interference effects, just to mention a few. Bearing in mind its lack of accuracy and crude model representation, one wonders why it is still the preferred method today.

4 PRESENTATION OF COMPARISON OF RESULTS AMONG, OTL – TERRAIN, ISO 9613-2 AND PUBLISHED MEASURED DATA.

4.1 Published measured data used as comparison reference.

The cases presented here are based on sound measurements taken and presented in the Delta Report of 2006, "Nord2000: Validation of the Propagation Model for The Danish Road Directorate"[10]. The few cases chosen and presented here were such that ISO 9613-2 calculations could be performed without any ambiguities and simple enough to allow an insight of the sound propagation mechanisms involved. Furthermore, since distance is a major parameter affecting results, it was decided to choose three different distance ranges where measured data were available. The last criterion, for the choice of the cases presented below, was the presence or absence of barriers between source and receiver. Based on the above criteria, the eight cases examined are presented in the following table:

Table 1: Cases used for the validation of NORD 2000 and implemented with ISO 9613-2 and OTL – Terrain. In some of the cases meteorological conditions are taken into account while flow resistivities of the terrain or barriers differ. Due to limited space here, the reader is encouraged to find more information at www.delta.dk.

Distance S - R					
4.5 m	Case 13	Case 17	Case 33	Case 36	
50 m		Case 91			Case 92
100 m	Case 77				
120 m					Case 40

4.2 Comparison results

In order to highlight the advantages of working in a three dimensional environment with advanced calculation methods, the results in this paper (extracted from OTL – Terrain) are presented in five frames. The frame template used is as follows:

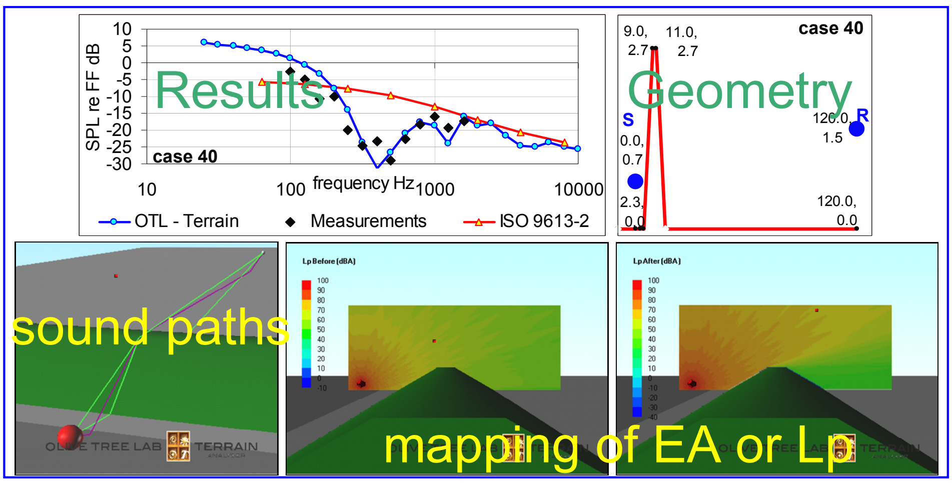


Figure 1: Template of the presentation of results (in colour). Mapping, using OTL – Terrain, is either done on vertical or horizontal planes depicting in some cases EA of ground, EA of barrier, level before and after the insertion of a barrier (such as above). The sound paths between Source and Receiver up to 3rd order diffraction are shown in the left bottom frame (extracts from OTL – Terrain). Case number is given in the graph and geometry frames.

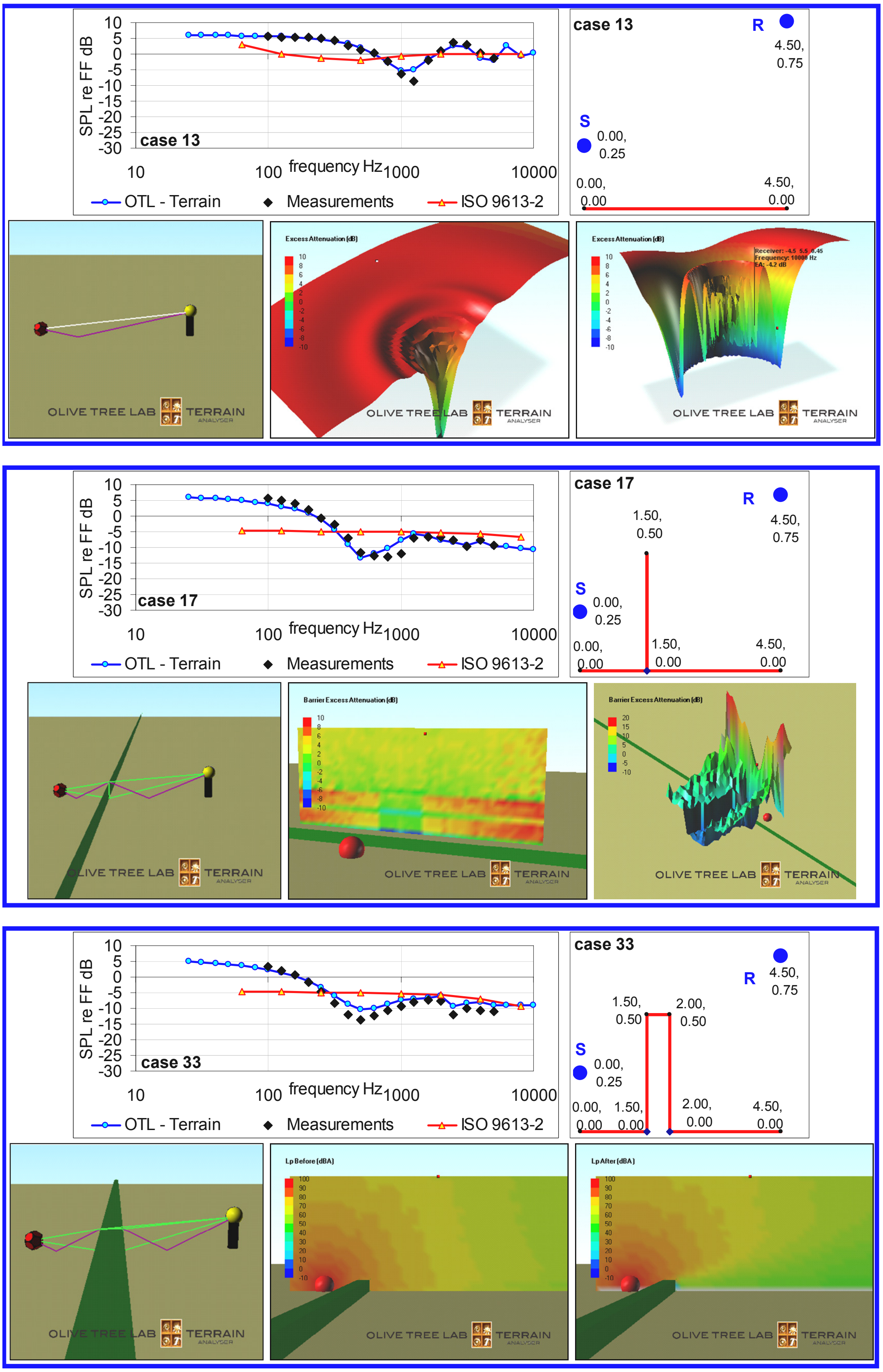


Figure 2: Results for cases 13, 17 and 33.

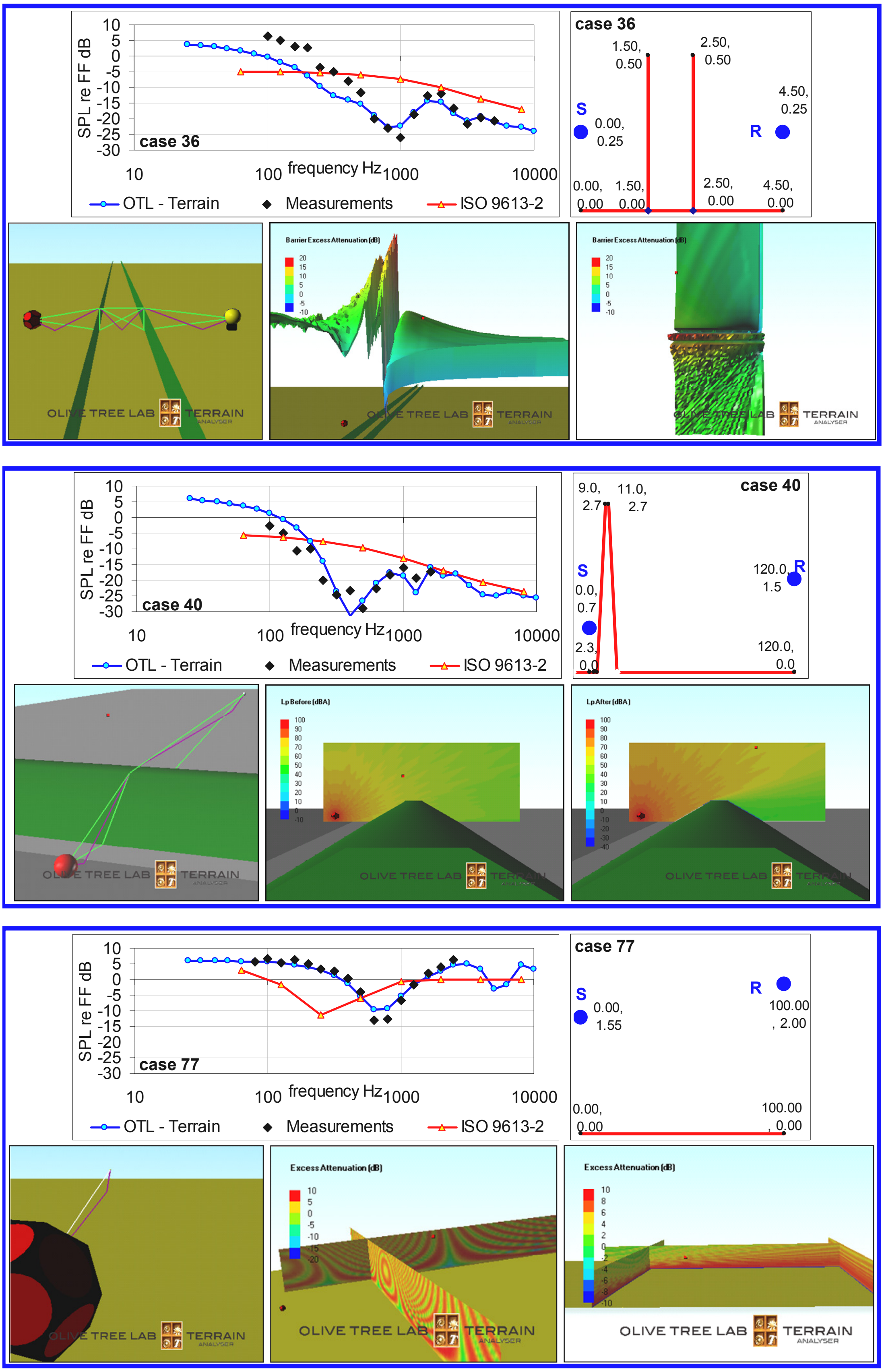


Figure 3: Results for cases 36, 40 and 77.

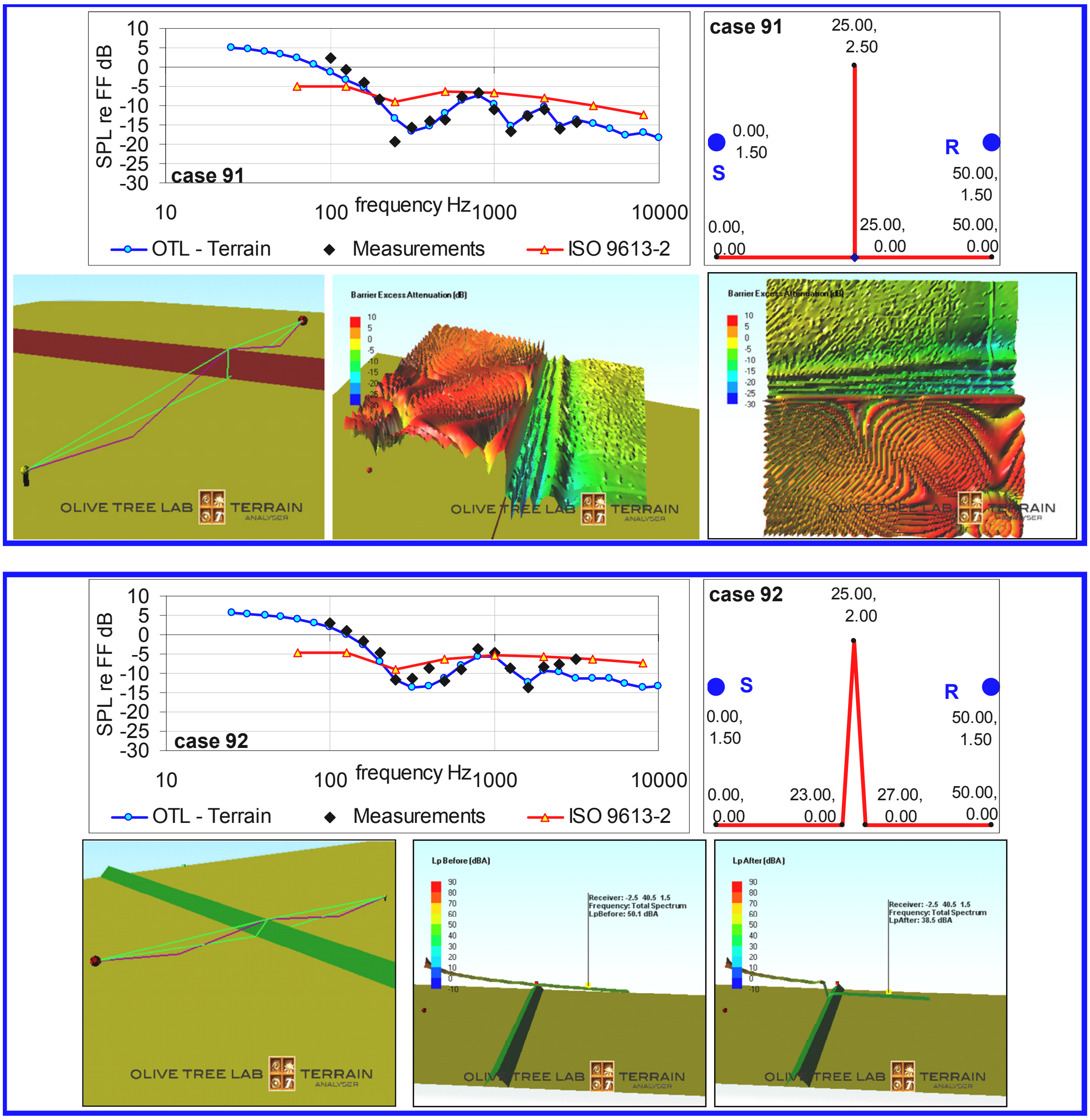


Figure 4: Results for cases 91 and 92.

4.3 Some results presented in various frequency resolutions

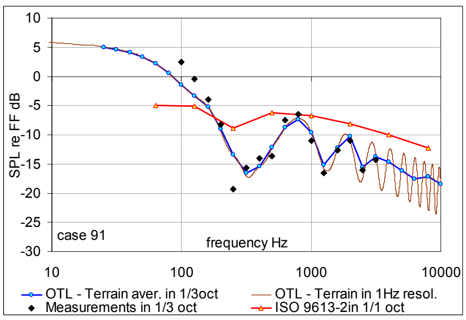


Figure 5: The importance of showing results in higher frequency resolution. The loss of coherency due to frequency averaging could be mistaken for meteorological smoothing, even though no turbulence effects are included in the calculations. At the same time octave bands provide very little information on the outdoor sound propagation mechanisms which come into play.

5 COMMENTS ON THE COMPARISON OF RESULTS.

L_{Aeq} results are not given or dealt with in this paper since the main objective here, is the investigation of the details of the analysis conducted by the ISO 9613-2 and more advanced calculation methods. If results suffer in the detail, broadband results suffer too.

5.1 Measurements data

In an effort to avoid any bias, it was decided to use as reference, the internationally accepted sound measurements results used to validate the Nord 2000 model. However, there is very little information available on the methodology used. The authors, were able to track down some of the cases, which are not included in this paper (but are included in the report by Delta) and are described by K.B. Rasmussen in his work “On the effect of terrain profile on sound propagation outdoors”[11].

K.B. Rasmussen in his paper mentions that in some cases there was some uncertainty about the choice of flow resistivity. Also, his original graphs are not precisely reproduced in the Delta Report. Furthermore, it is suspected that there might be some typographical errors in the same document since neither Nord 2000 nor Harmonoise models can reproduce some of the results. It can therefore be claimed that the data used as reference might in some cases include some errors. Nevertheless, the overall trend is apparent and correct.

5.2 ISO 9613-2 results

Other than the obvious deviations of ISO 9613-2 calculation results from sound measurements results, the other striking feature as a result of the comparison is the lack of detail which deprives the interpretation of the outdoor sound propagation mechanisms which come into play. On the other hand high resolution results from OTL - Terrain, allow for the interpretation of the sound propagation mechanisms that take place over ground and obstacles. Figure 6, shows case 91 and demonstrates the interference effects of ground and barrier superimposed on the diffraction effect of the barrier. Looking at the 1/3rd octave band results, one can see the smoothing out effect of frequency band averaging. This loss of coherency could be mistaken for meteorological smoothing, even though no turbulence effects are included in the calculations. To demonstrate this effect more clearly, the graph below on the left, shows the EA of barrier in high frequency resolution, with and without mild turbulence. The right graph shows the same calculations but averaged in 1/3rd octave bands. The averaging smoothing makes the EA of barrier and ground almost identical irrespective of the presence of turbulence in one of the calculations.

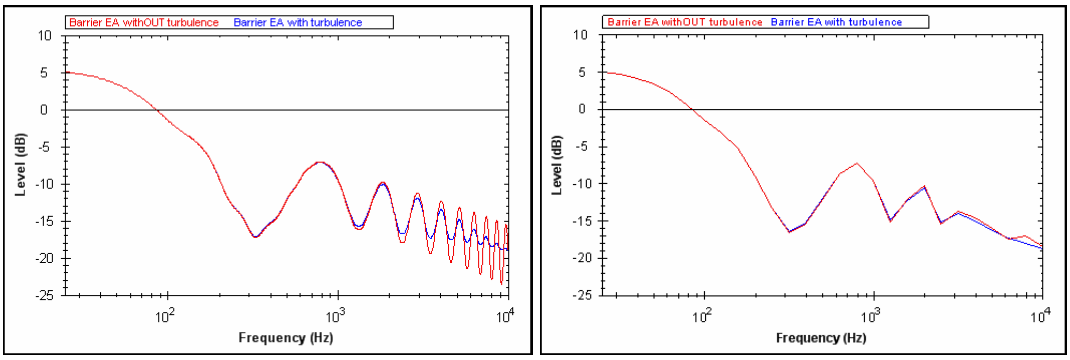


Figure 6: The loss of coherency due to frequency averaging makes the EA almost identical irrespective of the presence of turbulence in one of the calculations. On the left results in high frequency resolution where turbulence smoothing is evident, while on the right, averaging in 1/3rd octave bands makes meteorological smoothing indistinguishable from frequency smoothing.

A shortcoming of the ISO 9613-2 method, already mentioned, is the fact that the user could construct diffraction paths according to his understanding of the situation. In case 33, see below for the geometry, one could construct either a first or second order diffraction path from the thick barrier under study. There is ubiquity since the receiver is in the shadow zone of the first edge and in the bright zone of the second. The graph on the right shows how results can vary according to how one understands the problem.

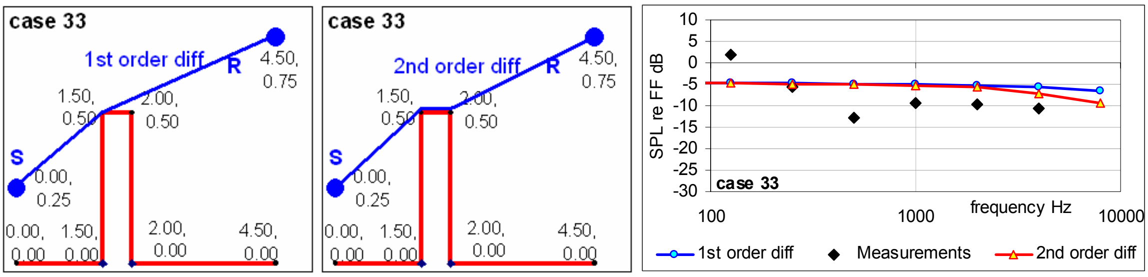


Figure 7: First and second order diffraction paths from the thick barrier provide different EA results.

5.3 Olive Tree Lab – Terrain results

The results of OTL - Terrain match fairly well with the measurements results but the authors anticipated a better agreement since the software application was validated against other measured data[12]. As mentioned above, there is limited information on the details of how the Nord 2000 validation data were obtained in order to fine tune the 3D models in OTL – Terrain. The authors themselves having conducted sound measurements to simulate other complex environments[13], are aware of the great detail that needs to go into documenting all the parameters for modelling outdoor sound propagation, especially geometry and materials flow resistivity. To demonstrate how results are very sensitive to modelling geometry, Figure 8 on the left shows mapping every 25cm on the horizontal plane, for case 36, at a height of 0.45m from ground (barrier height at 0.5m). There is an evident minimum in EA for the receivers on the axis between source and receiver at right angles to the barriers. Any deviation from it (to the left and right) provides significant changes. Figure 8 on the right demonstrates how a shift of just 5cm to the left off axis, can move results closer to the measurements values. On the other hand, 3D mapping allows one to observe that after a certain distance at right angles to the double barrier, there is no significant change in level. Levels increase considerably close to the barriers at an angle to the source.

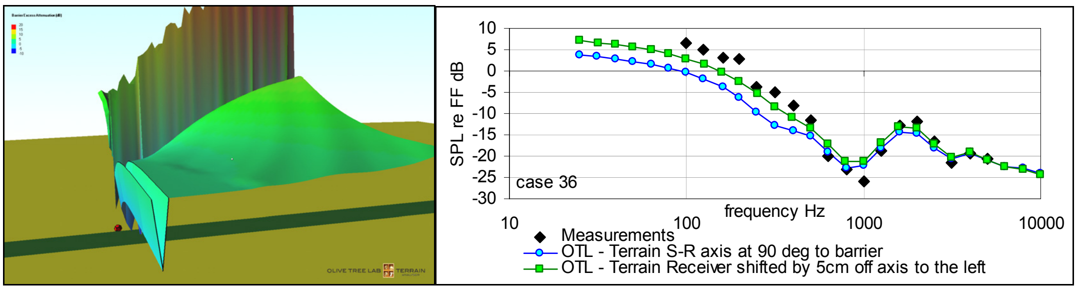


Figure 8: Modelling geometry could have a great impact on the results, especially in the lateral direction. A shift of the receiver to the left by only 5 cm provides a better match with measurements results. On the other hand, 3D mapping allows one to observe that after a certain distance at right angles to the double barrier, there is no significant change in level. Levels increase considerably close to the barriers at an angle to the source.

Another factor usually ignored in measurements studying sound interference phenomena, is the diffraction effects from loudspeaker cabinet units, a type of source reported to have been used in some of the measurements under study. This phenomenon contaminates sound measurements results by effectively turning one sound source into many sources (due to the generation of secondary sources with different phase shifts) thus introducing interference effects in the transfer function response with no available method for its removal. In fact, the use of many speakers or dodecahedrons should be avoided since they do not produce pure impulse responses due to the many sources at different distances from the microphone and their cabinet diffraction effects. A preferable method for outdoors is the use of fire crackers which produce a powerful omni directional sound wave.

6 CONCLUSIONS

ISO 9613-2 is an empirical method which is simple to understand and implement, widely used ever since its publication in 1996. It has served the acoustical community well, but this paper shows that it yields results which are inaccurate and imprecise.

Advanced calculations methods and models were around since the time of the ISO method publication. Technology of that time may have hindered their practical use in software applications. It seems that now it is the time to replace old empirical approaches and apply new scientific methods which allow the study of outdoor sound propagation mechanisms. There can be no dispute that more advanced methods offer better results. However, their implementation in software applications should offer more answers than questions. They need to be implemented in a way to assist the user and not the other way round. Every click of the mouse is a burden and should be avoided. The authors of this paper consider that a successful software application is the product with which one needs to spend the least possible time in solving a problem.

Mediterranean Acoustics Research & Development, has created an acoustical calculation engine which simulates sound propagation in a three dimensional environment with a possibility of eventually including all phenomena deemed important in acoustics. It utilises the principle of sound rays to detect sound paths. Currently a sound ray in OTL – Terrain, carries information on how to lose intensity with distance, how to interact with the atmosphere and how to reflect and diffract when it encounters objects. Eventually the sound ray will acquire sound transmission and refraction properties, thus the acoustical model would be able to analyse phenomena combining outdoor sound propagation, sound transmission and room acoustics at the same time.

One could enumerate some of the advantages of advanced calculation methods as follows: (a) They provide a unified approach in acoustics with one calculations engine to deal with most topics in acoustics. (b) They offer the ability to simulate complicated environments by using simple rules. (c) They apply accurate general solutions without vagueness to all scenarios, including special cases.

The main disadvantage of advanced calculation methods is that they are still computationally expensive. Furthermore, a better understanding of the science behind them is needed by end users for the proper interpretation of the results.

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