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VALIDATION OF A NUMERICAL CODE FOR EDGE DIFFRACTION BY MEANS OF ACOUSTICAL MEASUREMENTS ON A SCALE MODEL OF AN ANCIENT THEATRE

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Abstract

An efficient and reliable method to model edge diffraction is required in view of further developing the computer simulation of rooms. Despite the sophisticated numerical approaches already available a parallel experimental validation is needed in order to better understand the merits and efficacy of the edge diffraction modeling. In this work the Svensson-Andersson-Vanderkooy time domain modeling was tested by comparing with a set of experimental measurements taken in a 1:20 scale model of an ancient theatre. In fact the tiers of steps of an ancient theatre consisting of the cavea alone are an ideal benchmark to model edge diffraction. In this type of space the impulse response consists of two geometrical components (direct and floor reflection) and the tail is made up by diffracted sound only. In the work the 1:20 scale model of the Greek theatre in Siracusa was set up to meet this conditions. Although some geometrical limits of the numerical model in the version here employed, it was possible to correlate theoretical and experimental results under few conditions and for a number of seating positions. Within the above limits the edge diffraction modeling provided a reliable impulse response particularly in the lower part of the cavea.

Keywords:
Edge diffraction, scale modeling, impulse response

1. Introduction

In the acoustics of ancient theatres the interplay of the architectural components in the build-up of the sound field has raised interest across the centuries. The study of the geometry of these spaces of performance was also considered a valid knowledge in view of designing modern theatres. A few recent studies investigated the acoustics of ancient theatres and, in particular, in [2] and [3] the fundamental role of the wave phenomena, such as diffraction and scattering, has been outlined. Furthermore edge diffraction is one of the most relevant topics in the modeling of sound field in rooms, especially in view of implementing an advanced, efficient, physically based, edge diffraction algorithm into the acoustical CAD simulation programs.

Whereas the surface scattering has found a shared definition and the procedure for its measurement has also been established, the effect of edge diffraction, which is more complicated to analyze and model, is still the subject of several studies which mainly tackle the edge diffraction problem by means of detailed numerical approaches.

In this work a theory for the edge diffraction as reported in [6] was applied to model a tier of steps whose aspect ratio coincided with the steps of the Greek theatre in Siracusa, Italy. A 1:20 scale model of the same theatre was used to collect a series of acoustical measurements. In parallel numerical simulations were prepared for two setups of the main floor and a close comparison of simulations and experiments was accomplished.

2. Edge diffraction

The term "edge diffraction" refers to the sound which, impinging on a wedge composed of planar surfaces, is diffracted around it. In order to obtain continuity in the frequency representation of the impulse reflection from a finite planar surface it is necessary to consider the edge diffraction as a fundamental component of the sound field.

For instance in Fig. 1 the simple case of a right angle wedge is shown where three zones can be found: in zone 1 the direct, reflected and diffracted waves all arrive at the receiver, in zone 2 the direct and diffracted waves arrive at the listener but not the reflected ones and finally zone 3, where the listener in the "shadow zone", receives the diffracted waves only.

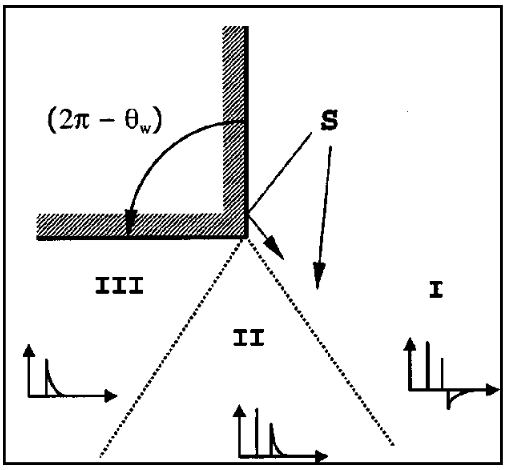

Figure 1 – Simplified scheme of the impulse response in the three zones around a wedge (after Svensson).

Given a source, a receiver and an object consisting in planar surfaces, it is thus possible to decompose the sound field into geometrical contributions and edge diffractions.

The former group includes the direct sound and the specular reflections whereas the diffraction comes out by the interaction of the wave with borders, angles and corners.

The most important contributions to the solution of the diffraction problem from a point-like source and a wedge can be traced back in the first place to the works of Biot-Tolstoy [4], take over by Medwin [5] and extended by Svensson et al. [6] for the first and second order of diffraction.

3. Measurements on a scale model

To test the model described in [6] a series of acoustical measurements was accomplished in the modular scale model (1:20 scale) of the ancient theatre of Siracusa [2]. The model was prepared in its most simple set up, that is with the "cavea" of the Greek theatre and without any stage building (Fig. 2). By doing so it was possible to isolate the scattering effect of the steps of the cavea. Moreover the measures were repeated both with sound reflecting and sound absorbing floor of the orchestra. Sound absorption was obtained with a porous layer and allowed to exclude the floor reflection and its subsequent diffracted contributions from the impulse response.

The measurement chain consisted in a spark as sound source, a B&K ¼" microphone and a reference microphone whose position was fixed to control/adjust for the amplitude of the spark.

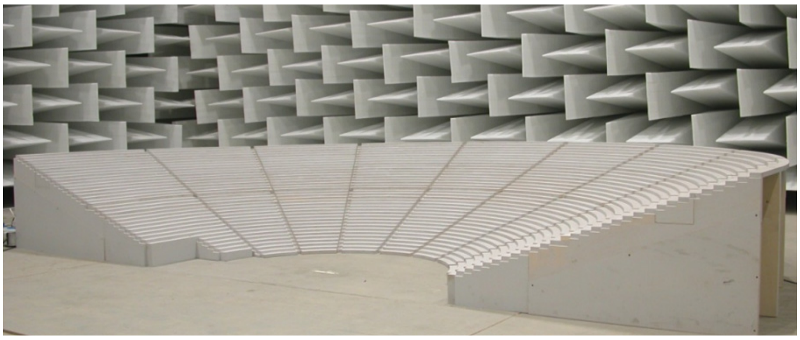

Figure 2 – The scale model of the Siracusa theatre inside the anechoic chamber.

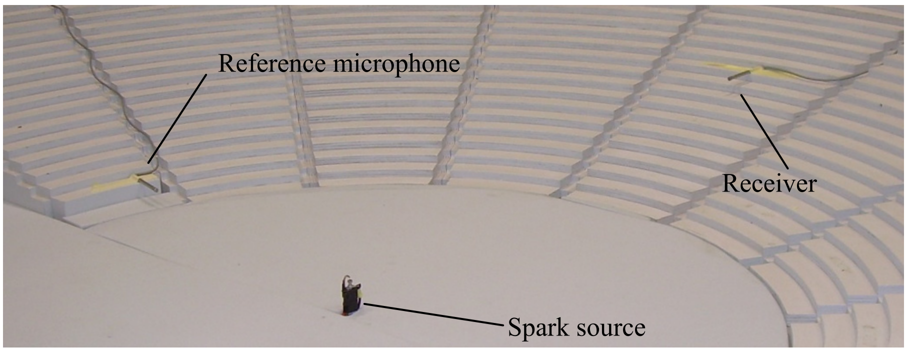

Figure 3 – Details of microphones and source with the sound absorbing floor.

A sound card with 192kHz sampling rate was adopted so that the useful frequency was 96kHz which, in the current 1:20 scale, matches a real scale frequency of 4.8kHz. The receivers have been placed on every step in the central slice of the cavea. An example of the positioning of the measurement microphone on the sound absorbing floor is shown in Figure 3. The impulse response, shown in Fig. 4 for both sound reflecting and sound absorbing floor, is able to neatly distinguish the first reflections from the subsequent scattered sound field coming from the steps.

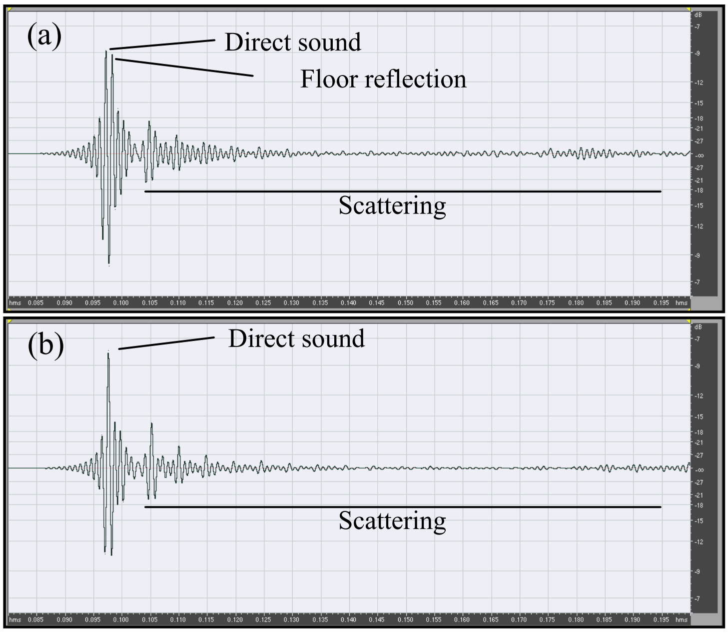

Figure 4 – IR for the spark in the case of reflecting (a) and absorbing (b) floor.

4. Numerical simulations

For the numerical simulations the code *EDBtoolbx* for the computation of the edge diffraction was used [7]. This Matlab toolbox consists in a series of functions that calculate the impulse response for a sound source placed in a space where rigid and flat surfaces are found. Specular reflections of any order are calculated, and the edge diffraction components up to sixth order and combinations of the above are included in the impulse response.

The use of this numerical tool requires two steps: firstly all of the valid reflection/diffraction paths are found by using the conventional image source method with enhancement for the edge diffraction, then for each valid path the reflection is added to total impulse response. For the contribution of diffraction the expressions reported in [6] are implemented.

The numerical code in the version adopted in the study works with plane surfaces only, thus it was decided to model a tier with steps having the same aspect ratio as those in the scale model. An alternative could be to mimic the round shape of the tier of steps with a set of planes arranged accordingly. Anyway the diffraction effect in this latter case would depend critically on the number of planes and the response could be quite difficult to investigate due to the large number of components introduced.

The sound source and the receivers were placed in the same positions occupied during the measurements and both conditions of the floor have been simulated.

Actually, the reflecting floor condition was obtained by placing a secondary source at the point of intersection of the ray coming from the image source with the floor. The spherical divergence was also taken into account.

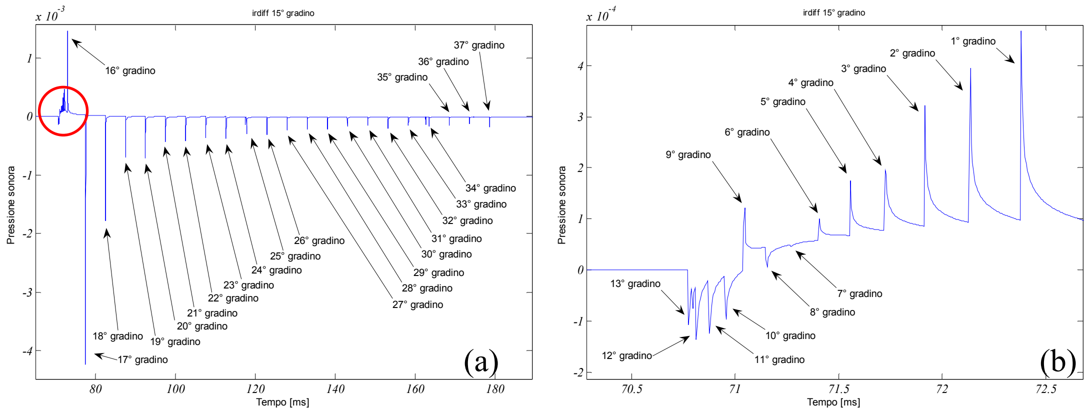

Figure 5 – The diffracted component in the simulated IR for the step (=*gradino*) 15. The single contributions from the other steps are outlined: (a) global view; (b) zoom of the first part (red circle).

The results for the diffracted component calculated for the step 15 in the condition of sound absorbing floor are reported in Fig. 5. For the sake of clarity the time scale in the a) and b) frames is different to highlight the contributions from the steps in front and behind position 15.

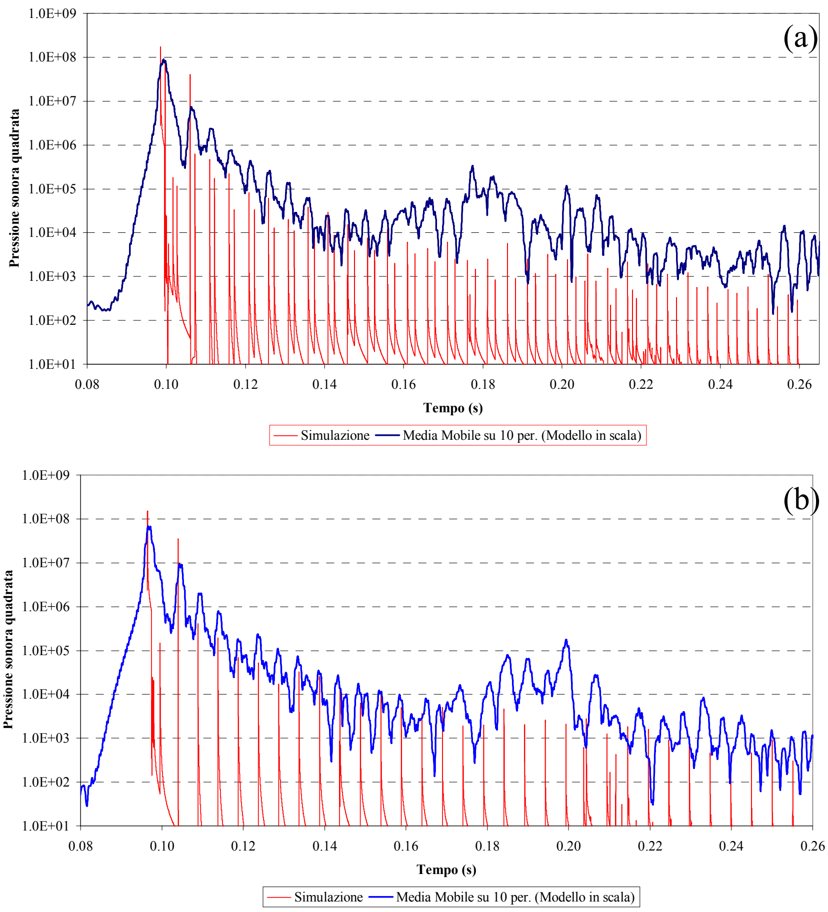

Figure 6 – Comparison between measure and simulation for step 5: (a) reflecting floor, (b) absorbing floor.

5. Discussion

In this paragraph the simulated and measured impulse responses, both squared, are analyzed. As regards the measured responses the running average upon 10 samples is used to make the direct comparison between the two data sets easier.

As an example in Fig. 6 the comparison for the step 5 with sound reflecting (above) and sound absorbing (below) conditions is reported.

A good correspondence between measures and simulations can be noted even if the discrepancy increases in the range 180 ms - 200 ms for both configurations. This finding can be attributed to the difference in the two geometries considered. The measures include also the contributions of the lateral parts of the tier, which is non modeled in the simulations.

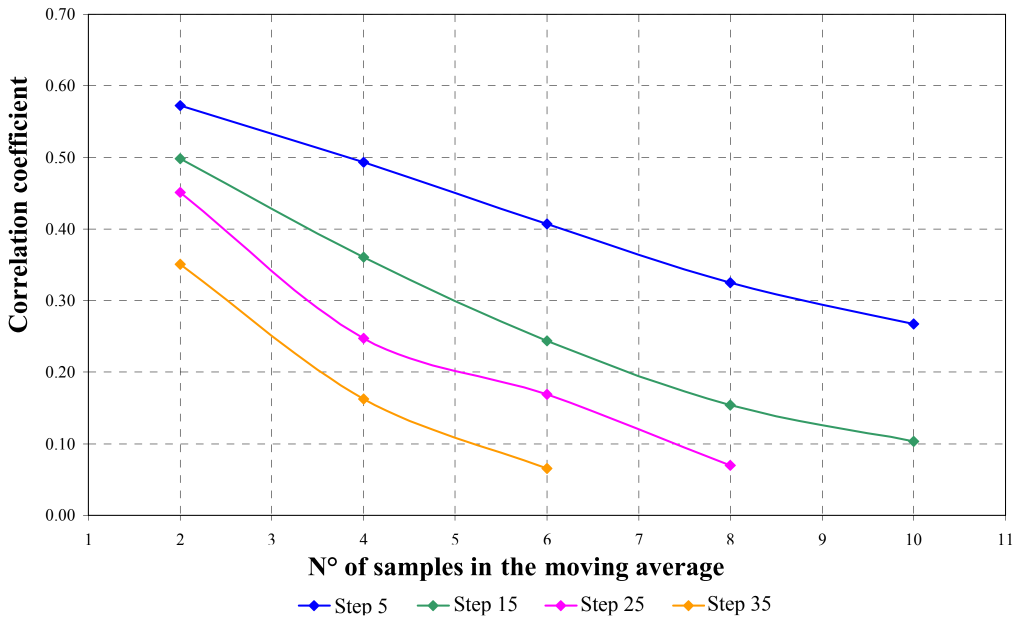

Figure 7 – Sound absorbing floor: trend of the correlation coefficient for several positions as function of the moving average.

Finally the correlation coefficient of the two curves was computed for a number of cases including different distances in both configurations, and points used for the running average. The results are presented in Fig. 1 for the sound absorbing floor and can be resumed as follows:

- The trend of the correlation curves is similar in the two floor cases and is decreasing when moving from the points in the first steps to the upper part of the tier. This result might be explained by recalling that when moving upwards in the tier the geometrical differences between the model and the simulations probably have a more severe impact on the results. In particular the decrease in correlation is due to the lack of lateral reflections in the simulation which are present in the scale model.
- When the reflecting floor is considered, the values undergo a global decrease. This can be justified partly by the normalization operated in order to accomplish the simulation of the diffracted contributions generated by the floor reflection. Actually it is believed that most of the discrepancy is still due to the non matching geometries. In fact in this case the discrepancy comes into play twice, once for the directed and

once for the reflected sound. The diffracted components due to both direct and reflected sound are in fact calculated for the straight tier instead of the circular cavea.

- When the number of samples in the moving average is increased the correlation decreases. Even though, the best results are always obtained for the closest positions and the other values are scaled according to the distance from the sound source. The correlation curves are almost parallel. The data for the reflecting floor are worse than those related to the sound absorbing floor.

6. Concluding remarks

A numerical model for the simulation of the edge diffraction was applied to the prediction of the impulse response in a tier of steps and the result have been compared with acoustical measurements in a scale model of an ancient theatre. At the time the work was done the modeled geometries had unavoidable discrepancy due to the impossibility of simulating a tier of circular steps. Even though, the work has outlined the effectiveness of the Svensson algorithm to simulate the edge diffraction. The diffracted components were correctly reproduced as regards the amplitude and the delay in particular for the lower steps whereas the farther positions showed some discrepancies which were primarily attributed to the mismatch in the geometries.

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