Roman Theatre Acoustics; Comparison of acoustic measurement and simulation results from the Aspendos Theatre, Turkey

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Abstract

Room acoustic measurements have been carried out in the best preserved of all Roman theatres, the Aspendos Theatre in Turkey. The results are compared with simulated values from a rough as well as a very detailed ODEON model of the theatre.

1. Introduction

In the context of a large, international, research project called "ERATO": "identification, Evaluation and Revival of the Acoustical heritage of ancient Theatres and Odea" funded by the European Union, acoustic measurements have been carried out in the Aspendos Theatre in Turkey.

The project is aiming at virtual restoration of ancient open and roofed Roman theatres and the purpose of the measurements in the Aspendos Theatre was to calibrate our room acoustic simulation model (created in ODEON). This model will later be used to auralize the sound in virtual presentations of what theater goers might have experienced in ancient times.

The Aspendos Theatre situated in the Southern part of Anatolia was built 155 a.d. and it seats about 7000 people. It is the best preserved of all Roman Theatres, as all parts of the structure are still standing in full height.

The measurements and simulations to be presented here concentrate on the room acoustic parameters described in ISO 3382. Among these, the strength, G, as a function of distance is believed to be a key parameter in this open space which at first was expected to generate little reflected sound energy. Besides, the degree of detailing in the model and the choice of diffusion coefficients is believed to influence the propagation over the empty cavea (the semi circular seating area).

Earlier studies dealing with simulation of Greek and Roman theatres exist [1], [2]; but we have not yet seen any direct comparison of measured and simulated data to guide us in how to generate a properly detailed and tuned computer model. It should be emphasized that the tuning of this model has not yet finished at the time of writing. Therefore, the simulated results presented here just indicate the current state of the model work.

2. The acoustic computer model

Two versions of the "Odeon" Aspendos model have been built: a rough version (362 surfaces) with the Cavea formed as sloping surfaces and only few details in the skene facade, see Fig. 1, and a far more detailed model (6049 surfaces) in which each step in the Cavea and all niches and columns in the skene facade are included, Fig. 2.

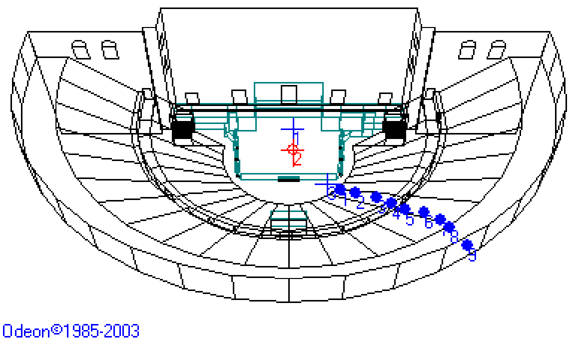

Fig. 1: Crude ODEON model of the Aspendos.

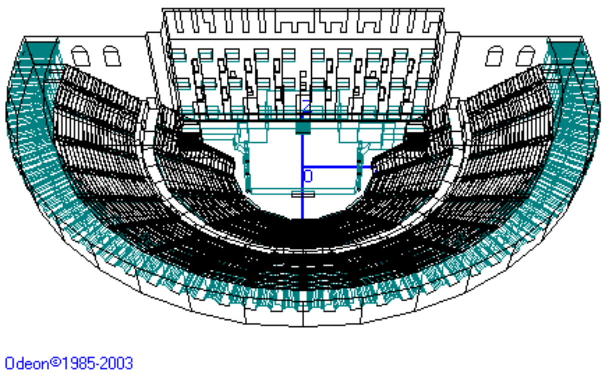

Fig. 2: Detailed ODEON model of the Aspendos.

Absorption coefficients of all surfaces were chosen after inspection on the site and subsequently adjusted until the simulated T values in the detailed model were roughly equal to the measured data. Thus, the current α values for the highly porous stone surfaces of the Skene façade and of the vaulted colonnade behind the cavea is 0.2, whereas the value for the more smooth and hard cavea is equal to 0.05 (constant with frequency in both cases). These absorption values were subsequently applied in the rough model as well.

As the theatre is frequently used for concerts and shows, it was equipped with a large mobile stage during our measurement visit. Consequently, this stage was also included in the two ODEON models.

3. Acoustic measurements

The “Dirac” software installed on a portable PC was used for most of the acoustic measurements. A two channel microphone with omni and Fig. 8 capsules (AKG C34) and a (custom built) omni directional dodecahedron loudspeaker with power amplifier were connected to the system via an external Edirol UA-5 sound card. The system was calibrated in a reverberation chamber at DTU (for the sake of the G-measurements) both before and after the trip to Turkey. (As we did not trust the calibration process of the Dirac system completely we also measured G more directly by means of steady state noise and a B&K 2260 sound level meter with octave filters. However, apart from deviations in the 125 Hz octave, the two systems gave similar results (within about one dB).

The measurement positions were chosen as points along each of two radial lines in the cavea, one line was placed in the left side of the theatre (seen from the audience) about 65° off the center line whereas the other line of receivers points formed an angle of 35° on the right side of the center line. For most of the results presented here, the source position was placed 2m to the right from the center line and about 15m from the Skene wall. These positions were also used in the simulations, and one of the lines of receiver points is shown as small dots in Fig. 1.

4. Results

In the following, the simulation results will be presented along with the measured data. In all graphs, measured data are marked by “Δ”, data from the detailed model by “□” and values from the rough model by “*”.

4.1. Reverberation Time, T

The position averaged values of Reverberation Time (T30) versus frequency are shown in Fig. 3.

First of all we observe that this theatre has substantial reverberation in terms of the rate of sound decay. It is also seen that whereas T in the detailed model follows the measured values quite well (as a result of the α modifications), T in the rough model comes out far lower – probably because the sloping cavea in this model quickly directs most of the reflected sound towards the totally absorbing “ceiling”.

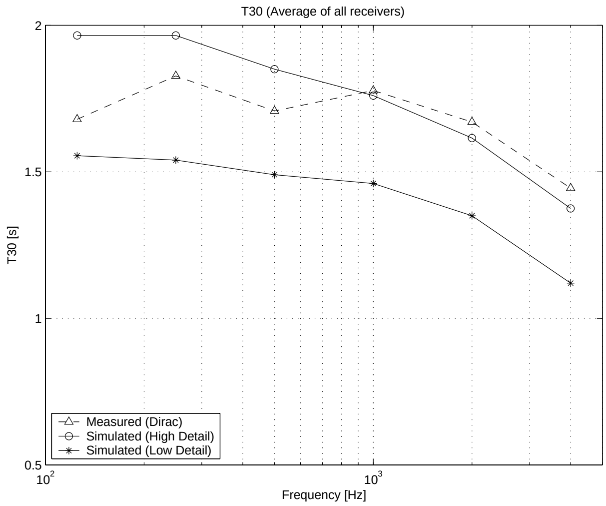

Fig. 3: Measured and simulated Reverberation Time versus frequency in the Aspendos Theatre (average of 16 receiver positions with source placed center stage).

4.2. Early Decay Time, EDT, versus distance

Also the EDT results from the rough model are far below the measured values as seen in Fig. 4; but here also the values from the detailed model are substantially lower than measured.

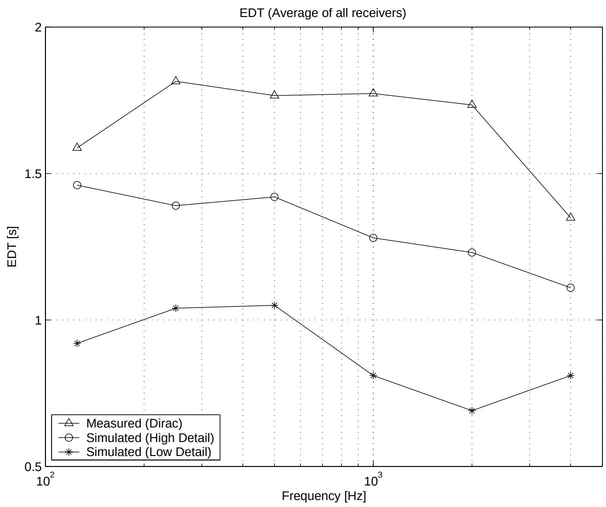

Fig. 4: Measured and modeled Early Decay Time versus frequency in the Aspendos Theatre.

As EDT often varies with position, the 1 kHz octave values have been plotted against source receiver distance in Fig. 5. All three sets of data are represented by two curves, one for each of the lines of receiver positions described earlier. I all cases the source was placed center stage.

The results from both models agree with the measured data that in general EDT increases slightly with distance; but the measured difference between the two lines of receiver points at distances below 30m are not reflected in any of the models. Besides, the general offsets between the measured data and the two models as described in Fig. 4 are seen to be highly significant compared to the variation between receiver positions.

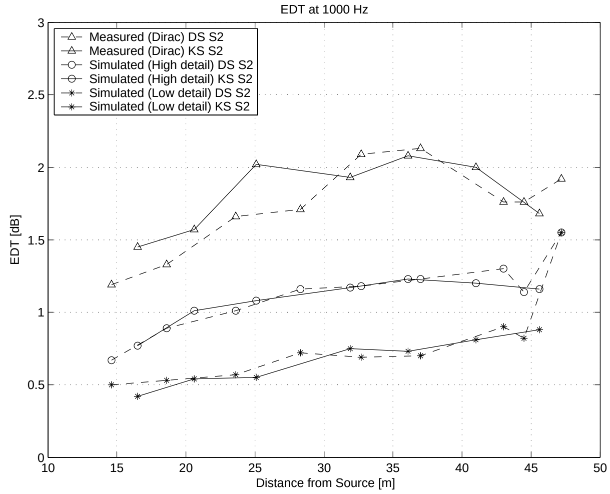

Fig. 5: Early Decay Time at 1000 Hz versus distance in the Aspendos Theatre

4.3. Strength, G, versus distance

In connection with measurements and simulations in the line of receiver points shown in Fig. 1, an alternative source position in the orchestra area and near the front edge of the cavea was also used as we expected it to be a tough test for the models to predict the attenuation with distance for grazing sound incidence. However, as seen in Fig. 6, this turned out not to be the case as the values from both the rough and the detailed model closely follow the measured data.

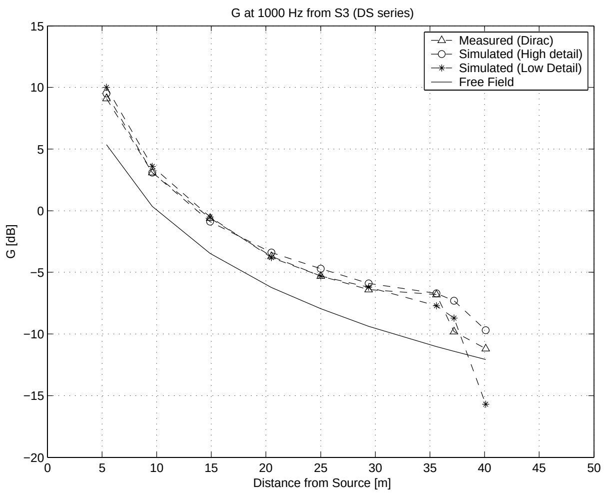

Fig. 6: Strength at 1000 Hz versus distance in the Aspendos Theatre. Source in orchestra. Full line without points corresponds to G in free field.

Only in the 125 Hz band, substantial deviations between simulations and measurements occurred; but these could well be due to measurement calibration problems, as the curves were simply offset from each other.)

The lower curve in fig. 5 indicates the theoretical value of G in a free field. It is seen that the measured and predicted level is at least 2-3 dB louder; but the attenuation with distance is almost as steep as for the direct sound alone, i.e. far steeper than the about 1 dB per 10m which, according to Barron's revised theory [3], would have been expected beyond the critical distance (equal to about 12 m) in a closed room with similar volume (about 80,000 m^3) and reverberation time (1.75 Sec.).

The average reverberant level is also lower than the -2 dB predicted according to empirical models based on experience in concert spaces [4].

4.4. Clarity, C, versus distance

The measured and ODEON simulated values of Clarity (C80) at 1kHz versus distance are illustrated in Fig. 7. Like in Figure 5, the data for each of the two lines of receiver points are shown separately.

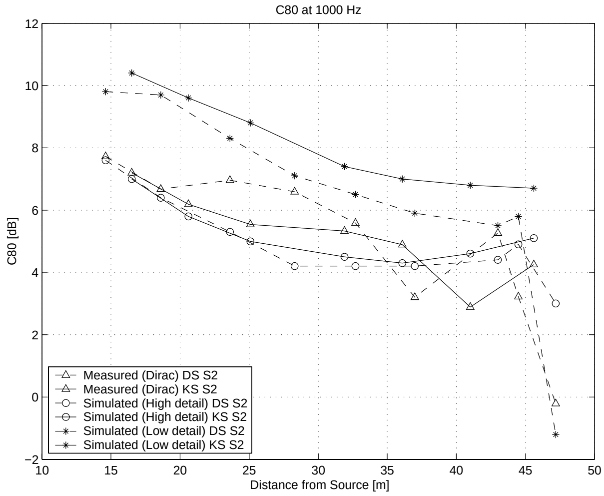

Fig. 7: Measured and simulated Clarity (1kHz) versus distance in the Aspendos Theatre.

As observed for the reverberation time, the detailed model is better than the rough in matching the measured data; but the fit is not too impressing. Still, the deviations between measurements and the detailed model are not systematic as seen for EDT.

The average C value being about 5dB is certainly high compared with the expected value of -0,6 dB in a closed room with a purely exponential decay and similar T. Taking into account the large width of the theatre (about 100 m) and the steeply sloped seating, higher C values can be expected according to regression formulae derived from experience in closed halls [4]; but even this empirical approach would suggest the position averaged C to be no higher than 3 dB.

5. Discussion

Although the tuning of the model(s) to improve the fit to the measured data is still in progress, the differences between measured and predicted results reported here are probably typical for what can be achieved. Thus it is likely that adjustment of model parameters to obtain a better fit of one acoustic parameter may result in larger differences for other parameters.

Besides the degree of geometrical detailing and the absorption coefficients, also the choices of the diffusion coefficients and the reflection order at which the calculation method goes from an image model to pure ray tracing can influence the simulation results substantially. The possibilities of adjusting all of these variables - in a meaningful way - have not yet been exhausted.

6. Conclusions

The soundfield in the Aspendos theatre is characterized by a considerable long reverberation time and Early Decay Time, EDT, but compared with roofed theatres or concert halls, the sound strength, G, is low and the clarity of the sound, C, (and presumably the speech intelligibility) is high due to a low level of the reverberant field - obviously caused by the absence of a ceiling.

Regarding computer simulations of the theatre, we have found it important - at least when modeling the empty theatre – to include the actual steps in the cavea as otherwise the T and EDT values turned out far too low. However, at least in the current state of development, also the detailed model gives too low EDT values. Contrary to our expectations, both models are capable of predicting the attenuation of level with distance from the source with proper accuracy in all octave bands above 125 Hz.

In the aural presentation, we hope also to be able to present values of RT in the occupied theatre, values of the Speech Transmission Index, STI, and perhaps even some live recordings and ODEON auralizations from this fine ancient theatre.

7. Acknowledgements

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8. References

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