The acoustics of the recently excavated Larissa Theatre A

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ABSTRACT

The work describes the acoustic properties of one of the two ancient theatres that existed n the city of Larissa, in Thessaly in central Greece. The first was initially excavated in 1910; since 1977, a more systematic project has been initiated to expose and preserve this monument. This theatre was initially built in the first half of the 3rd century B.C., within the ancient city at the foot of the fortified ancient acropolis. The theatre consists of the orchestra having a diameter of 25.5m (compared to 20m for Epidaurus), the cavea is divided in 11 sectors each with 25 tiers of seats and a partially preserved stage building is also in existence.
The work, presents a first record of the acoustics of this monument based on in-situ measurements based on: (a) an omnidirectional microphone to derive the acoustics parameters of the Theatre and (b) with a binaural dummy head to derive the binaural responses and allow subsequent virtual soundscape auralizations. The results of these measurements are also compared to other ancient Theatres.

Keywords: ancient theatre acoustics, acoustic measurements, excavations

1. INTRODUCTION

The First Ancient Theatre of Larissa is the largest Theatre in Thessaly, having a capacity of 10,000 people. It is located in the city centre of the modern city of Larissa, in central Greece and was constructed in the first half of the 3rd century BC. In period, it was located at the southern foothills of the hill "Fortress", where the ancient city's fortified Acropolis stood. An earthquake in the late 2nd century or early in the 3rd century AD destroyed the second floor of the scene, the Doric entablature and a part of the transcendent epitheatre. Almost its total destruction was induced by a second strong earthquake that occurred in 7th century AD[1].

According to long-time head of the Ephorate of Antiquities and the monument's excavator, the archaeologist Athanasios Tziafalias, [2,3] the theatre had a lifespan of six centuries, from the early 3rd century BC until the late 3rd or early 4th century AD. During the first centuries, apart from theatrical performances, the assemblies of the senior regional authority were hosted, the so called "Koinon" of the Thessalians. In the 2nd c. BC the Romans converted it into an arena, reserved for the official celebrations. Subsequently, the theatre was gradually buried, notably so after the 1868 earthquake.

In the early 20th century, the then Ephor of Antiquities Apostolos Arvanitopoulos began excavations that revealed part of the scene ("skene"). After the Second World War blocks of flats constructed directly on the theatre's surface, which during the 1980's were compulsory demolished so that a gradual unearthing began that lasted until the mid-2000s.

Several monuments from different eras were found in close proximity to the Theatre, such as the smaller second ancient Theatre, the basilica of St. Achilles, etc, evidence to the city's continuous habitation throughout the centuries.

Today, the First Ancient Theatre of Larissa (Fig. 1) has been unearthed almost in its entirety. Its cavea ("koilon") is built on a natural hill side and is divided by the diazoma, a 2 m wide corridor, into the main theatre and the "epitheatron", the cavea's lower and upper section respectively. The main theatre was divided by 10 staircases ("klimakes") into 11 cunei, where each cuneus ("kerkida") consists of 25 rows of seats ("edolia"). When the theatre was converted to an arena, the three first rows where removed and their marble seats where repurposed to retain the upper rows. To this day, only a small part of the epitheatron is preserved. The orchestra has an estimated diameter of 25m and is surrounded by a closed conduit, the "evripos" that runs under the foundations of the eastern and western rooms of the scene building. The retaining walls ("anallimata") are maintained in excellent condition, although still not fully unearthed.

The Scene building ("Skene") is one of the best preserved and perhaps the most luxurious of the few examples of this category of Hellenistic buildings that survive. It is pre-served in situ, retaining numerous architectural elements of the colonnade that forms the Proskenion, and the

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drystone masonry that forms the side rooms. The Proskenion is made of marble and the rooms are made of limestone and marble blocks without the use of mortar. The stones' origins are traced in the ancient marble quarry of Kastri (Melfos V., 2010) and limestone quarry of Tirnavos (Melfos V., 2011). Throughout the centuries several architectural elements, especially limestone blocks were removed and used as building materials, and can now be found in nearby historic buildings of the early Byzantine and Ottoman eras [1].

2. MEASUREMENTS

2.1 Measurements

The first set of acoustic measurements followed the approach of previous work in the ancient theatre of Epidaurus [5]. The measurements' positions are placed in three different rows and in three different angles 5^0, 45^0 and 85^0. An additional set of 5 measurements was conducted on cunei D since this section retains the most well preserved seatsthough those measurements are not presented and analysed in the current work. A list of the positions is given in Table 1 and in Fig. 1. In Fig. 2 there it is shown the measurement equipment during the preparation of the measurements.

These measurements should be considered as preliminary, as the restoration of the main theatre - by means of repositioning ancient and installing new seats - is not yet finished and in front of the skene, there was an obstacle (a crane truck of 8x2.5x1.6m used for lifting the marble seats, in the scope of the restoration works). Although this crane was placed about 4m from the skene façade and the sound source was about 8m far from the truck, another set of measurements is scheduled after the restoration is finished.

Three types of measurements were conducted: (i) via an omni free field microphone for calculating the acoustical parameters (ii) via a binaural head for calculating IACC and for further virtual auralizations and (iii) via a Sound Pressure Level meter for direct measurement of the sound pressure level differences and the ambient noise. The sound source was producing white noise signal of 100dBA at 1m. Table 2 gives a list of the equipment used for the measurements.

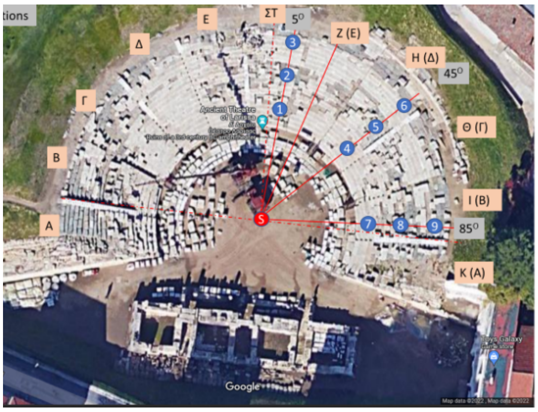

Figure 1 – Top view of the theatre showing the measurement positions (blue dots) and the sound source position as the red dot [6]

2.2 Ambient Noise

Since the theatre is located in the centre of the city of Larissa and behind the skene which is below the ground level, there are many taverns and cafeterias which were closed at the time of the measurements. However, noises were present from passers-by and wind, affecting mostly measurements at the upper positions, near the hills' top. The wind gusts mostly affected the binaural measurements since as the rest of the microphones were equipped with wind shields. In general, the SNR of the measurements is greater than 30dB.

Table 1 – Measurement positions

Position	Distance (m)	Angle (deg)	Row (number)
R1	20	5	5^{th}
R2	25	5	12^{th}
R3	30	5	17^{th}
R4	20	45	5^{th}
R5	25	45	12^{th}
R6	30	45	17^{th}
R7	20	85	5^{th}
R8	23.5	85	11^{th}
R9	27	85	15^{th}

Figure 2 – Preparation of the measurement setup. It consists of the KEMAR binaural dummy head, the omnidirectional microphone and the SPL meter.

Table 2 – Measurement equipment

Item	model
Sound card	RME Babyface
Free Field mic.	PCB 377A40
Binaural mic.	G.R.A.S. KEMAR
SPL meter	NTi Audio XL2
SPL Meter mic.	M2210
Sound Source	Mackie Thumb 15BST
Calibrator	G.R.A.S. Type 42AB

3. DATA ANALYSIS & ACOUSTIC INDICES

3.1 Single channel responses

The free field measurements were performend using REW [7] software and a log sin. sweep signal of 10sec duration [8]. The sound source was set at 100dB at 1m for a 1kHz sinewave. The recordings were at 44.100Hz and subsequently the responses were exported using a Half Hanning window of 3 seconds. The measured impulse responses (IR) *h(t)* were imported to Audacity [9] for analysis and calculation of the Acoustics Parameters, using Aurora Acoustical Parameters available in Aurora plug-ins package [10].

The acoustical parameters calculated are, D50 (%), C80 (dB), STI/RaSTI and frequency response, as presented in the following sections.

3.2 Calculation of the acoustical parameters

The Acoustical Parameters are calculated in accordance to ISO3382 [11] as also mentioned in [10].

The Definition index for speech signals (D50%) is defined as:

$$D50(\%) = \frac{\int_0^{50ms} h^2(\tau)d\tau}{\int_0^{\infty} h^2(\tau)d\tau} 100 \qquad (1)$$

The Clarity for music C80 (dB) is defined as

$$C80(dB) = 10\log\frac{\int_0^{80ms} h^2(\tau)d\tau}{\int_{80ms}^{\infty} h^2(\tau)d\tau} \qquad (2)$$

The RaSTI index is defined as:

$$RaSTI = [S/N + 15]/30 \qquad (3a)$$

Where S/N is the signal to noise ratio defined as:

$$S/N = 10\log\frac{\int_0^{95ms} a(t)p^2(t)dt}{\int_{95ms}^{\infty} p^2(t)dt} \qquad (3b)$$

Where *α(t)* is the contribution of the signal to the measured sound pressure level and *p(t)* is the measured sound pressure level.

The STI is calculated using the Modulation Transfer Functions method described in [12].

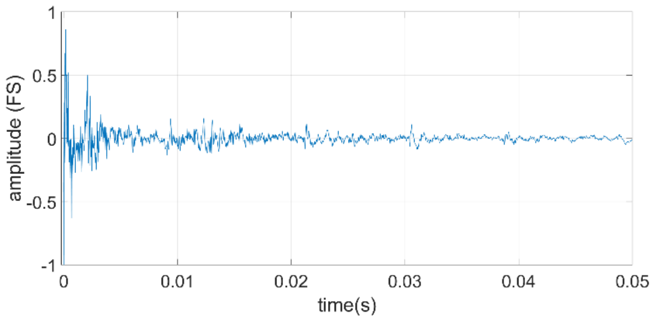

Figure 3 – Typical IR for position R1(first 50ms)

3.3 Binaural responses

The Binaural impulse responses were recorded using Audacity [6] and processed using the Aurora plug-ins utilizing the Binaural dummy head option for the analysis [7]. The excitation signal is a sign sweep of 10s duration at a sampling frequency of 44.100 Hz.

From the binaurally recorded impulse responses $h_L(t)$ and $h_R(t)$ the normalized Interaural Cross Correlation (IACC) was evaluated as:

$$\Psi_{yl,r}(\tau) = \frac{\int_{t=-\infty}^{+\infty} y_l(t) * y_r(t+\tau)dt}{\sqrt{\int_{t=-\infty}^{+\infty} y_l{}^2(t) * \int_{t=-\infty}^{+\infty} y_r{}^2(t)\, dt}}$$

with the internal delay τ, and left and right sound pressure signals, $y_l(t)$ and $y_r(t)$[13].

4. RESULTS

4.1 SPL vs distance

Figure 4 presents the measured SPL reduction with distance. The variation of SPL with distance is comparable to that measured for Epidaurus [5], noting that here the measurements were restricted to the maximum distance of 30m as opposed to the longer distances for Epidaurus (almost 60m to the far position).

4.2 Acoustic Indices

4.2.1 Clarity and Definition

As can be observed from Figs.5 and 6, both Clarity and Definition were found to be exceptional and independent of distance and angle.

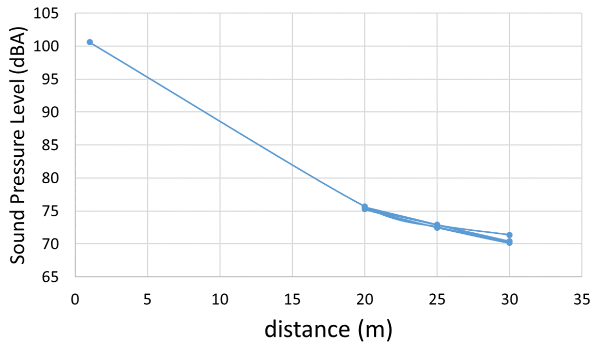

Figure 4 – SPL vs distance measurement

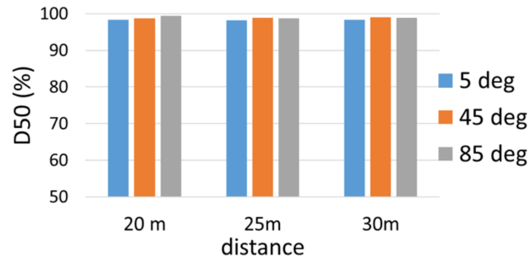

Figure 5 – D50 (%) for the measurement positions.

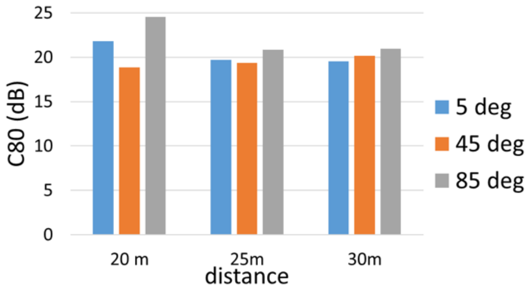

Figure 6 – C80 (dB) for the different measurement positions.

4.2.2 Speech Intelligibility

Speech intelligibility is predicted to be excellent and largely independent of distance or angle. For the longest measured distance, intelligibility is even slightly improved, a result of the higher contribution from reflection / diffraction from the lower tiers.

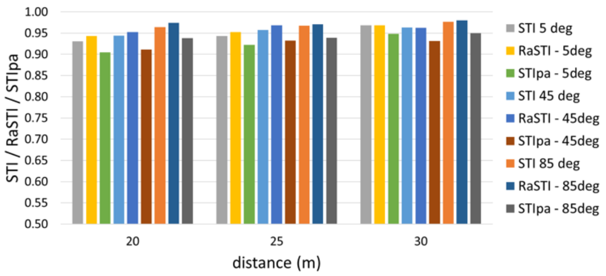

Figure 7 – The various Speech Intelligibility Indexes for the different measurement positions.

4.3 Frequency domain analysis

4.3.1 Response spectra

The response in Fig. 8 shows a rather more even characteristics than other measured theatres. The typical dip around 180Hz (due to the orchestra floor reflection) is present but the dominant peak around 1KHz is still present but rather less prominent than the spectra measured in Epidaurus [5].

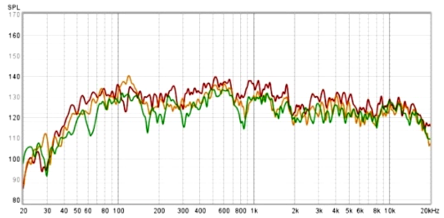

Figure 8 – Frequency responses for the 3 different angles and the nearest positions (R1-R4-R7).

4.3.2 Clarity for speech vs frequency

Figure 10 shows the mean clarity for speech (C50) over frequency for three different distances from the sound source. It is obvious that this parameter does not vary significantly with the position and even for the far away positions, the clarity of speech is expected to be at very good level

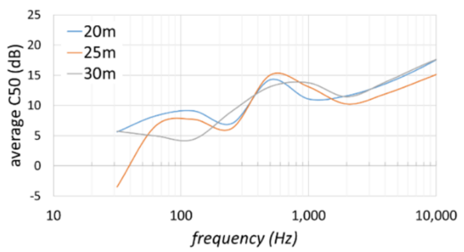

Figure 10 – Mean C50(dB) versus frequency for the same angles and for the different distances

5. CONCLUSIONS

The Ancient theatre of Larisa A, after its recent unearthing and ongoing restoration was thoroughly measured here and provides evidence for brilliant acoustics for speech transmission. Although the theatre is placed in the centre of a modern city, the background noise did not affect the acoustic performance of the theatre.

This first measurement session produced data from free field microphone and a binaural dummy head, able to fully characterize the acoustics of the theatre and create virtual auralizations. Measurements are also planned for a latter stage of the on-going restoration to record the acoustics of a fully restored cuneus and scene of the theatre.

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