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Past challenges in the study of ancient open-air theatre acoustics

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ABSTRACT

Over hundred ancient open-air theaters are still standing in Turkey. Acoustics of these theaters are of great interest and attract attention by visitors. Within the scope of a pilot study completed in 1995, three ancient theaters in the Mediterranean region were investigated. Measurements were made in these theaters, namely, Termessos (Hellenistic, Pisidia), Perge and Aspendos (Roman, Pamphilia). An impulsive sound source was used to record sound on a portable tape recorder at audience locations to be later analyzed in the laboratory on computer, upon analog-to-digital conversion for comparison to simulation results. This paper addresses then-challenges faced in conducting measurements in these spaces located sparsely in the country side. Ways to confront and overcome problems of the lack of electrical power and transportation infrastructure, and difficulties to cope with meteorological conditions have been detailed. Insufficiency of analysis and simulation tools is also outlined. Lastly, these historical amphitheaters are comparatively discussed in this paper by introducing a contemporary amphitheater in Central Anatolia. Although, this contemporary case is architecturally reminiscent of a classical Roman amphitheater in its initial design, the construction had ended up with a shelter over seating area, providing a semi-open space, and a disputable sound field.

1. INTRODUCTION AND METHOD

1.1 Ancient Theatres

Acoustics of ancient open-air theatres is said to be satisfactory for most seating places, although their seating capacities can vary is from a few hundred to a couple thousand. Only a few studies on acoustics of ancient theaters are devoted to the causes of good acoustics. Neither acoustic measurements nor detailed acoustic analyzes were discussed in these studies for theaters in Asia Minor and ancient theaters elsewhere before 1990. The main reason for studying the acoustics of ancient theaters by including computer simulations based on geometric room acoustics was the lack of extensive research on this subject. It is also believed that uncovering the reasons for good acoustics will serve as a powerful tool in the design of new outdoor theaters.

The most important and oldest surviving research on the acoustics of open theaters is recorded by M. Vitruvius Pollio [1]. A historical survey had been conducted to define locations, capacities and conditions [2] of possible candidates for this detailed study. The theatres of Aspendos, Side, Perge and Termessos were originally selected for measurements. The proximity of the theatres to each other and their well-preserved status appeared to be the prominent factors which supported this selection. Side, Aspendos, Perge are Roman theatres in Pampfilia while Termessos is well-known Hellenistic period theatre in Psidia. Side Theatre was omitted from the study as acoustical measurements would not be performed at Side due to presence of intercity bus terminal nearby, capable of producing high levels of unsteady background noise(Table 1).

1.1.1Acoustical Measurements in Theatres

An impulsive sound source was used as the source of excitation. Sound measurements were conducted in these theaters by recording analog signals on ½ inch magnetic tape. An instrumentation tape recorder (RACAL STORE 4DS) equipped with two FM channels and powered by a portable car battery was employed in data acquisition. Two -half inch free-field microphones (B&K 4165) with GenRad preamplifiers were employed in data acquisition. A sample measurement microphone positioning at D2 in Aspendos and Perge is illustrated in Figure1.

Table 1 Theatre Information

	Perge	Aspendos	Termessos
Normalized Average Distance (NAD)	0.54	0.63	0.52
Seating Capacity	13595	9054	4199
Number of Receiver Positions	20	25	20

Analog recordings of acoustical pressure signals collected from several receiver positions in theatres with no audience were to be later analyzed in the laboratory on a DataGeneral MINC-23 minicomputer after Analog-to-Digital Conversion process, in the laboratory at ME Department of METU in Ankara. Temperatures varied from 12 to 21.5 degrees Celcius while the wind speed fluctuated between 1.6 m/s and 2.4 m/s during the measurements taken in successive years of May 1989 and May 1990. Relative humidity was fairly constant about 50%.

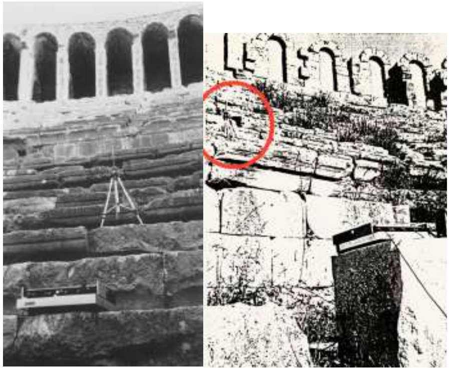

Figure 1 –Microphone Positioning at Aspendos and Perge Theaters

Configuration of receiver locations is shown in Figure 2 for AspendosA typical response to impulsive excitation in Aspendos Theatre is displayed in Figure 3 for a selected receiver location coded D2.

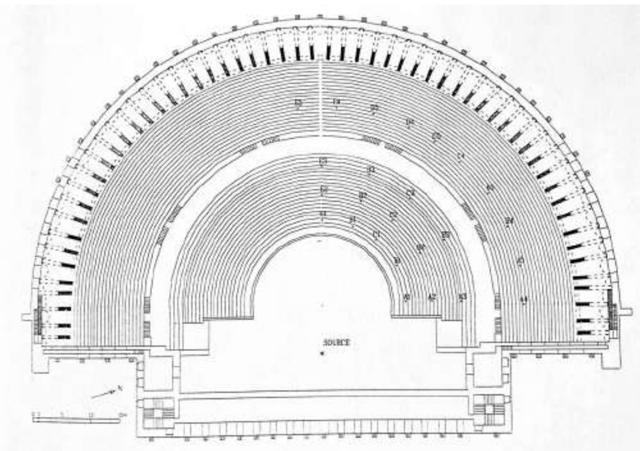

Figure 2 – Assigned Receiver Locations in the Theatre of Aspendos.

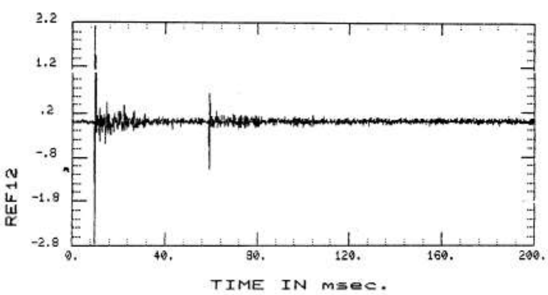

Figure 3 – Measured Impulse Response in the Theatre of Aspendos at Recevier Position D2.

1.1.1 Simulations

Sound reflections from orchestra surface and stage walls were simulated by both ray tracing and method of image sources. Reflection patterns obtained from analytical and experimental studies were evaluated and receiver positions with and without echoes were determined. A three dimensional model was devised for analysis of sound field due to image sources. The direct and reflected paths of sound formed as tetrahedron. Dimensions of Termessos Theater was used in the model.

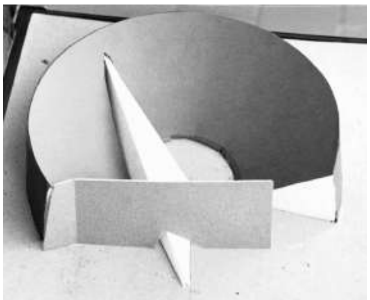

Figure 4 – Three-dimensional tetrahedron model of direct and reflected rays of sound.

Acoustical characteristics in these three theatres were simulated by method of image sources by home-grown software at ME Department of METU. Impulse response characteristics of theatres were obtained from simulations for specified source-recevier pairs (Figure 5, Figure 6).

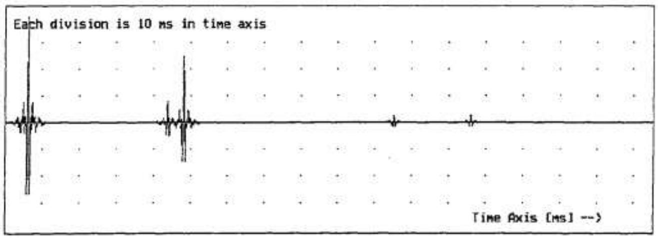

Figure 5 – Simulated Impulse Response from Reflection Pattern by Method of Images, Aspendos Theatre Impulse Response Receiver Position D2.

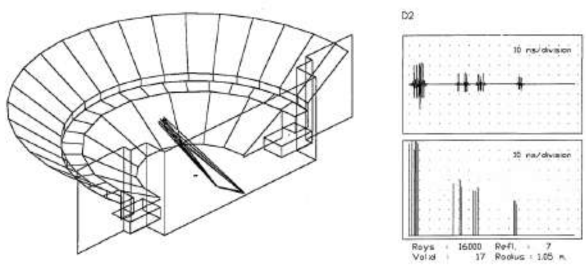

Figure 6 – Simulation by Ray Tracing, Aspendos Theatre Impulse Response Receiver Position D2.

1.1.2 Evaluations of Results

The main findings of the study with respect to acoustical design characteristics of the Aspendos, Termessos and Perge theatres can be summarized as follows:

- The significance of the skene and orchestra surface is pronounced; these architectural elements have an important role on the reinforcement of the direct sound by the strong first order reflections.
- The semi-circular forms of the ancient theatres are very suitable for reducing normalized average distance. This characteristic is important, especially, for open-air theatres from the standpoint of shorter direct sound paths. The sloped auditorium forms an advantage for increasing the hearing angle.
- The side walls of the skene are observed as problematic surfaces with respect to practical sound source locations on the orchestra. These surfaces cause the undesirable late reflections. Hence, to minimize this effect, these components should be covered by absorptive materials in the possible future uses of ancient theatres. The portable surfaces should also be positioned on these side walls in order to change the reflection-angle.
- The lack of ceiling cover in the form of an orchestra shell in open-air theatres studied is a drawback. However, a temporary or portable can be constructed for the future-use of ancient theatres. According to the characteristics of performances, the reflectors can be formed and angled.
- The theatre of Aspendos is shown to possess superior acoustical characteristics on basis of slope, hearing angle, stage back wall height, smooth orchestra surface. Excellent to very good speech transmission index figures were obtained through simulations even in the unoccupied uses of all three theatres while Aspendos possesses the best figures.

1.2. A contemporary case: Bilkent ODEON, Ankara, Turkey

In contemporary age the performance spaces either open, semi-open or closed are mostly used for multifunctional activities, due to economic considerations. This is one of the basic challenges for room acoustics designers in this era. One example is a semi-open amphitheater Bilkent ODEON, which is a gathering place for speech related activities including school ceremonies, or large-scale meetings as well as a performance place of orchestral music and recitals. ODEON with 4000 seating capacity is designed to serve Bilkent University's and the capital Ankara's educational and artistic activities.

The amphitheater was initially built as a fully open space, but later in order to accommodate performances under harsh climatic conditions a curvilinear roof is added to the structure as a sheltering element (see Figure 7. The Amphitheatre's architecture, while reminiscent of a classical Roman amphitheater, highlights the features of high technology with its steel structure roof covered by a textile membrane, besides glass and a cable network system. The architectural form is a synthesis of two architectural styles separated by 2000 years. Although, the form and the synthesis of architectural styles results in an innovative building typology, the acoustical problems have arisen after the addition of this technological roof. Mostly concave and sound reflective roof membrane has caused multiple sound foci positions and thus un-even distribution of sound within audience seats. The structure has studied in previous years for possible acoustical interventions by field test tuned acoustical models [1,2].

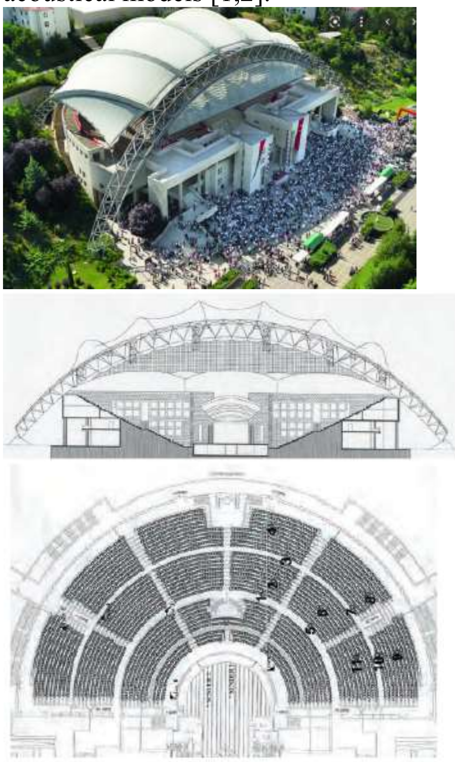

Figure 7 – Bilkent ODEON; arial photo (on top), section view (in the middle), plan view with source receiver positons (at the bottom)

The computer simulation of the hall for the unoccupied condition is performed using ODEON 6.01 (in 2006). comparison of the real-size measurements for the unoccupied hall to computer modelling in the same condition of occupancy for model tuning. The second simulation is made for the fully occupied (present) hall, which is much crucial as much closer to the real conditions.

For the occupied state and for its current conditions the average T30 of the hall for mid frequencies is estimated to be 3.05 s, while the average is 6.67 s for unoccupied hall. The uneven distribution of the sound is observed in distribution maps (see Figure 8), which supports the present complaints by the audience.

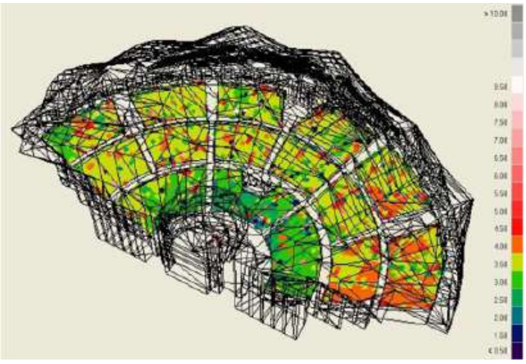

Figure 8 – Early decay time distribution map for 500 Hz and for the fully-occupied hall, Bilkent ODEON

The problems were even greater before the current state. As in order to heal the harsh reflections and hot spots sound absorbing acoustic fabrics are partially attached in between steel trusses at the back zone. However, this treatment has not yet satisfied the desired acoustical quality of the hall (Figure 9). The overall form of the roof has to be re-shaped otherwise sound absorptive treatment application has to be widely applied under the PVC membrane. In order to prevent acoustical hazards caused by the shelter creating an immense volume underneath, it is a necessity that the sound absorption area should be drastically increased. Maybe, in this era too we should respect the mostly open tradition of ancient amphitheatres settled at the hill sides, and leave the audience open to the atmosphere and fed by the direct sound arriving from the stage only.

Figure 9 – Interior view showing the sound absorptive panels at the rear zone of the amphitheatre

2.CONCLUSIONS

In this paper, the striking difference in the analysis results of ancient and modern day open-air theatres gives clues to challenges faced 30 some years ago. These challenges will be grouped and addressed below:

a. Analog versus digital instrumentation:
Inflexibility of analog means of measurement in those old days is a major drawback challenging researchers.
b. Deficiency of infrastructure:
Electrical power was not available in all three theatres. The measurement team had to rely on battery powered instrumentation. 12-VDC car battery was the only option for the researchers
c. Transportation: Some of these theatres were located at the top of the hills as the cities they serve were setup at high altitude and in distant places due to security issues. Reachability as well as transporting the measuring equipment posed major problems when the theatres were visited for measurements. The size and weights of equipment were much bigger than the digital counterparts.
d. Early days of simulation tools:
Simulation software was in the development phase. Researchers had to abort to “homemade” software lacking calibration and justification. Theoretical basis for some simulations were under development.
Even with all these drawbacks it was still possible to analyse the acoustics of such structures of the past. It was possible to point out locations where acoustical problems could be faced.

3.REFERENCES

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