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Contemporary Sound Environment around Ancient Greek Theaters: Current operation problems

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The ancient Greek theater dropped a long run of about 7 centuries and spread to the coast and the hinterland of the wider Mediterranean area. Starting with servicing the Dionysos ritual and drama contests, the Greek theatre followed the political and social transformations of the Greek-speaking world of antiquity. The Theater is, in fact, a scientific field, the limits of which are dispersed into different scientific areas. As an unfortunate consequence of this prominent location (and the various historical adversities), the interdisciplinary approach of the ancient theater and the multi-parametric dimension of its problems were neglected by modern research. The revival of ancient drama (from the early 20th century) and the demand for return to its natural space (for about a century) has prioritized the issues of reversible interventions to ensure the proper conditions for the performances.
Despite the serious distortions brought about by common Roman interventions or destructions caused by time, in most cases the reuse of the theatres is deemed feasible. However, the restoration efforts are incomplete without corresponding acoustic interference, as the modern sound environment (especially the traffic noise) exerts destructive nuisance on outdoor acoustic comfort, while the various stage-design solutions normally fail to activate the natural (passive) acoustic potential of the theatre space.
The paper is part of a broader research (ongoing since 2004), aiming at monitoring the contemporary status of the ancient theatres in Greece. The whole survey sample includes a sum of seventeen (17) theatre spaces. The parameters of the research include the integration of the theatres into the contemporary urban reality, the operational infrastructure, the sound environment and the acoustic evaluation of their current or potential reuse.

Keywords
Ancient Greek theatres, background noise, current operation

1. Introduction

Theatrical monuments of antiquity, due to diachronic conversions, are palimpsests of successive building phases, which correspond to very diverse social and cultural periods: the interpretation of the ruins, the restoration and the fixation of the surviving structures (many of which belong to destructive interference during the Roman period) are in conflict with the requirements of reliable reuse of the theatre space [1].
The popular tendency for revival of ancient drama (which almost exclusively concerns drama plays of the classic period) and the request for returning the performances in their natural setting (developed during the course of the 20th century), has prioritized the issues of mild interventions in order to ensure the necessary conditions for theatrical function. In most cases, the disagreement about the reuse usually focuses on fixing the parts of the *koilon* (cavity), on installing the modern infrastructure facilities, but primarily on protecting the orchestra and the ruins of the ancient stage building from the contemporary arrangements of the *scenographie* [2], [3].
During a performance, the requirements of the actors and the audience share the common goal of uninterrupted theatrical contact: support the theatrical inventiveness and the acting expression, provide the acoustic liveliness and the speech intelligibility of the space. As evidenced by many historical information, the ancient Greek theatres succeeded to accommodate large capacities under optimal visual and acoustic comfort (without, of course, any electro-acoustic amplification

during the authentic conditions of use). As it is also proved by numerous acoustic surveys (especially the ones of the second half of the 20th century) basic design principles have been successfully applied, serving the distinctive acoustic behaviour of open spaces, meaning [1], [4], [5]:

-acoustics protection (elimination of the exterior noises)

-harmonious development of the audience around the performances in the measures of the human voice and the hearing capacity (architectural forms of open floor plan)

-emergence of the direct sound and activation of a natural (passive) loud speaker thanks to positive, early reflections (mainly from the orchestra, the scenery and their combination)

-ensuring conditions of low resonance, grace to the deterioration of negative, late reflections (no roof, planned elimination of most side walls and elaborate enhance of the diffusive behavior of the remaining solid building components).

The famous acoustics of the ancient Greek theatre is due to the amplified acoustic response of the space which is related to the initial intensity of the original message. It is a process that ensures the replacement of the energy loss (due to outdoor sound propagation) in low reverberation (suitable for theatrical speech intelligibility) thanks to early, strong though of a limited number sound reflections, especially in the highest seats of *koilon* [2], [4], [6].

This audio quality is due to the apparent "emergence" of the theatrical message (when delivered by vocal trained and experienced actors) and involves two independent but closely related acoustic conditions: the apparent sound level difference between the useful signal and the background noise and the clear distinction of the successive parts of the linguistic chain. In the function '*time – sound intensity*', the emergence of the message appears like the tip of the iceberg on the sea of noise, in other words, it is the visible part of the sound energy that is not distorted by background noise. The physical size of the acoustic emergence, in global or frequency values, depends on the fundamental acoustic evaluation of the response of the space as the spectral density, the energy ratios direct / total intensity, the early decay of sound energy and the reverberation time which are all connected to the basics subjective criteria of acoustic quality as the *colorization* and the *intimacy*, the *clarity* and finally the *intelligibility* of speech [1], [7].

Every permanent or temporary parasitic sound nuisance of the acoustic communication is called *'background noise'*. The contemporary environment is dominated by traffic and urban noise which are usually much stronger than the natural ones. Especially in outdoor theatres unforeseen or knee-jerk reactions of the public (whispers, coughs and movements) must be taken under consideration. The background noise covers a portion of the useful signal interpolating constantly or occasionally a kind of sound *mask.* The gravity of this masking phenomenon is proportional to the level and frequency spectrum of the parasitic signal. Generally, noises deform the higher frequencies of the useful signal. Noises with a broad or continuous spectrum tend to nullify the whole speech in the case they affect the middle frequencies (700 - 1000 Hz) which are more effective for human hearing [8].

During the theatrical communication, the masking of the message is a complex psycho-acoustic process, which is related to the visual comfort or the hearing angle of each spectator. Pure tone noise, even with high intensity (up to +10 dB) has a negligible effect on speech. Nevertheless, when the noise spectrum shifts from high to low frequencies, the acoustic effects of the coating become subjectively important. It has been established that the parasitic signals of the continuous spectrum may eliminate the intelligibility of speech, even in low levels intensity circumstances (minus 20dB lower than the intensity of the useful signal). According to this analysis, the values of sound emergence in theatrical space are evaluated according to the following behavior: optimal (> 25 dB), good (20 - 25 dB), moderate (15 - 20 dB), and non acceptable (<15 dB) [7], [8].

2. Research data

This paper is part of a broader research (ongoing since 2004), aiming at monitoring the current status of the ancient theatres in Greece (modifications, destruction, protection works, sound source and levels of environmental noises in deferens scales) and evaluating their acoustic quality in contemporary operation conditions. The whole survey sample includes now a sum of seventeen

(17) ancient Greek theatres: Argos, Delphi, Dion, Athenian theatre of Dionysus Eleftheреus, Dodoni, Epidauros, Eretria, Thassos, Thorikos, Mantineia, Maroneia, Megalopolis, Messini, Larisa, Orchomenos of Veotia, Philippi, Amphiaraion at Oropos. At a later stage, the research will be extended to theatres in the Greek islands.

THEATER	Use	Koilon	Orchestra	Scene
A1 Athens Dionysus	B4	C4	D2	E2
ENVIRONMENT – NOISE LEVELS F2 (44-65), F5 (48-54), BN 37				
A2 Thorikos	B2	C2	D5	E1
ENVIRONMENT – NOISE LEVELS F3 (48-54), F7 (37), BN 34				
A3 Oropos	B2	C5	D2	E4
ENVIRONMENT – NOISE LEVELS F7 (36-38), BN 33				
A4 Eretria	B3	C5	D4	E3
ENVIRONMENT – NOISE LEVELS F4 (42-47), F7 (39-41), BN 37				
A5 Delphi	B3	C2	D2	E2
ENVIRONMENT – NOISE LEVELS F4 (41-48), F5 (38-52), BN 33				
A6 Orchomenos	B2	C5	D3	E2
ENVIRONMENT – NOISE LEVELS F1 (42-46), F3 (52-57), BN 41				
A7 Argos	B2	C1	D1	E2
ENVIRONMENT – NOISE LEVELS F1 (42-44), F2 (44-48), BN 37				
A8 Epidauros	B1	C2	D6	E2
ENVIRONMENT – NOISE LEVELS F5 (44-48), F7 (34-38), BN 29				
A9 Megalopolis	B3	C5	D6	E5
ENVIRONMENT – NOISE LEVELS F6 (51-55), F7 (40-42), BN 39				
A10 Mantineia	B3	C5	D3	E2
ENVIRONMENT – NOISE LEVELS F4 (50-55), F7 (41-43), BN 36				
A11 Messini	B2	C5	D6	E5
ENVIRONMENT – NOISE LEVELS F3 (44-48), F7 (39-41), BN 35				
A12 Larisa	B3	C4	D2	E2
ENVIRONMENT – NOISE LEVELS F1 (54-64), F2 (62-70), BN 43				
A13 Dion	B1	C6	D6	E2
ENVIRONMENT – NOISE LEVELS F4 (44-48), F7 (41-43), BN 38				
A14 Dodoni	B3	C3	C2	E3
ENVIRONMENT – NOISE LEVELS F6 (34-38), F7 (33-35), BN 27				
A15 Philippi	B1	C3	D2	E2
ENVIRONMENT – NOISE LEVELS F4 (50-54), F7 (42-46), BN 40				
A16 Thassos	B1	C6	D3	E2
ENVIRONMENT – NOISE LEVELS F7 (36-38), BN 33				
A17 Maroneia	B2	C4	D3	E2
ENVIRONMENT – NOISE LEVELS F3 (44-48), F7 (35-39), BN 34				

TABLE 1. The sample of seventeen (17) ancient Greek theatres

The survey data is briefly recorded in **Table 1**, which includes:

-in column A the location of each theatre,

-in column B the current use of the theatrical space, with typical entries: B1 for official festivals, B2 for occasional performances, B3 for temporary ban due to restoration works and B4 for permanent performance prohibition,

-in column C the status of the *koilon*, with typical entries: C1 for carved in rock, C2 for full restoration, C3 for full restoration including Roman interventions, C4 for partial restoration including Roman interventions, C5 for damage by illicit stone traders C6 for damage by illicit stone traders - partial intervention with wooden gradients.

-in column D the status of the orchestra, with the typical entries: D1 for Roman conversion into water tank, D2 for Roman coating, D3 for damaged, D4 for preserved *charoneion* (underground) passage, D5 for incomplete configuration, D6 for preserved condition

-in column E the status of the scene, with typical entries: E1 without any kind of building, E2 for damaged building and foundation ruins, E3 for *hyposcenium* (low stage building) ruins, E4 for colonnade of the *proscenium*, E5 for *scenea ductilis* (infrastructure of mobile stage),

-in each line, labeled “environment – noise levels”, the contemporary environment of each theatrical monument is recorded, with the typical entries F1 for various urban activities [in dB. max L], F2 for urban traffic [in dB(A) Leq,h], F3 for agricultural activities [in dB max L], F4 for ring road and highway traffic [in dB(A) Leq,h], F5 for tourist and amusement activities [in dB max L], F6 for restoration activities [in dB max L], F7 for natural environment [in dB(A) Leq,h] and BN for undefined background noise [in dB min L].

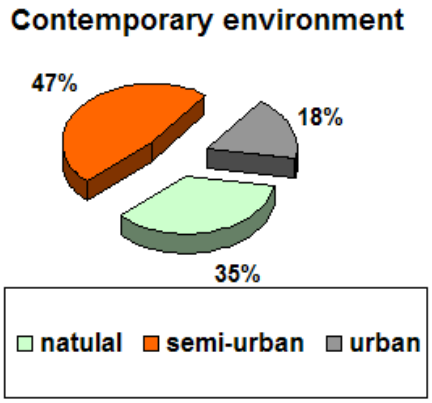

FIGURE 1

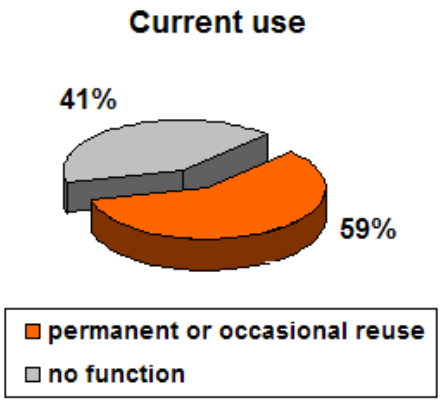

FIGURE 2

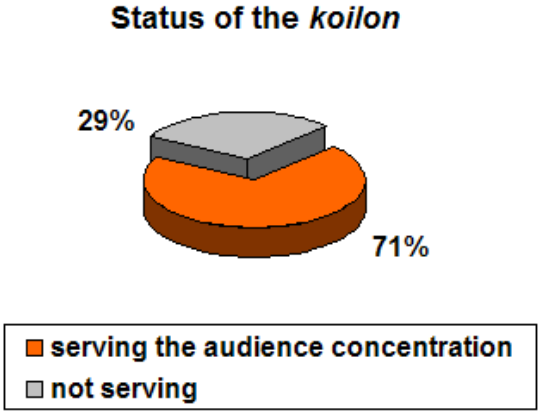

FIGURE 3

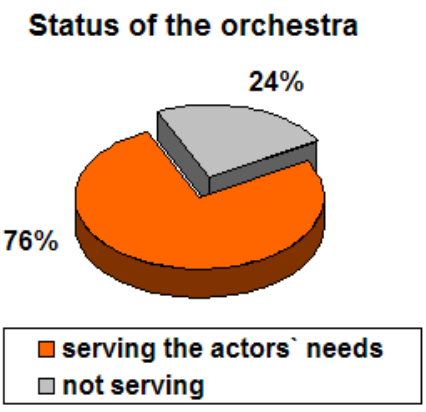

FIGURE 4

As shown in a first approach to the data of ancient Greek theatre sample:

-the existing environment is not, basically, surrounded by nature (only 35%, 6/17) **(Figure 1)**

-59% (10/17) theatres are operating on a permanent or occasional basis **(Figure 2)**

-71% (12/17) theatres are serving the concentration of the audience in full or limited security **(Figure 3)**

-76% (13/17) spaces have full or limited service infrastructure installations **(Figure 4)**

-82% (14/17) theatres have only visible ruins of the diachronic structures of the scene building **(Figure 5)**

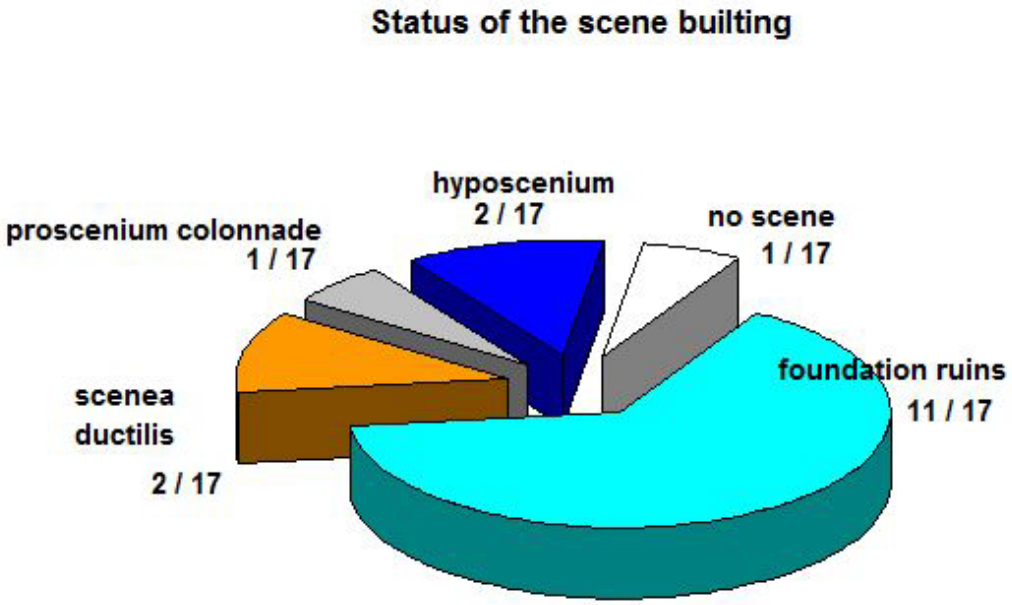

FIGURE 5

3. The acoustic evaluation of sample

In order to understand the effect of the environmental noise, it is appropriate to make some clarifications. The limits of the enforced silence adopted in different places for distinct function [ıe 25 dB(A) in areas of high cultural interest or 35 dB(A) in residential area] result from the standard frequency curves of international noise criteria (NC) corresponding to the average hourly statistically equivalent sound level. However, the theatrical function in outdoor conditions is a peculiar and fragile acoustic circumstance where feasible or infeasible communication depends not only on the statistical equivalent part of the environmental nuisance, but often (especially at crucial moments of the theatrical action) from the occasional (rhythmic or irregular) occurrence of a noise. Therefore, in a rather conservative approach of the sound nuisances during a performance, it is preferable to correct the hourly equivalent sound level (*Leq,h*) by the maximum expected value of noise (*Lmax*).

Noting the number of discrete and measured noise sources (excluding the indeterminate back ground noise BN, Lmin) of the sample, we find the following circumstances (in brackets the noise levels in the interior of a theater):

-3 urban activities [maxL: 51-70 dB(A)]

-3 restoration activities [max L: 36-53 dB]

-4 ring road and highway traffic [Leq,h: 47-52 dB(A)]

-5 urban traffic [Leq,h: 55-65 dB(A)]

-5 tourist and amusement activities [max L: 44-48 dB]

-8 agricultural activities [max L: 44-52 dB]

-17 natural environment [Leq,h: 34-42 dB(A)]

Based on these distinctions, **Figure 6** depicts the incidence of each source to the total of forty-five (45) distinct sources of the sample and the grouping of sources depending on the occasional or the permanent (periodic or continuous) character of the noise nuisance:

-occasional sources 17 (38%),
-permanent periodic sources 16 (35,5%),
-permanent continuous 12 (26,5%).

As shown by the dispersion of the sources of the sample, a small proportion (26.5%) corresponds to a continuous, permanent nuisances of high sound level, while in the majority of the circumstances occasional or periodic sources which are easy to control or ignore (relative with background noise of a normal outdoor performance) are detected.

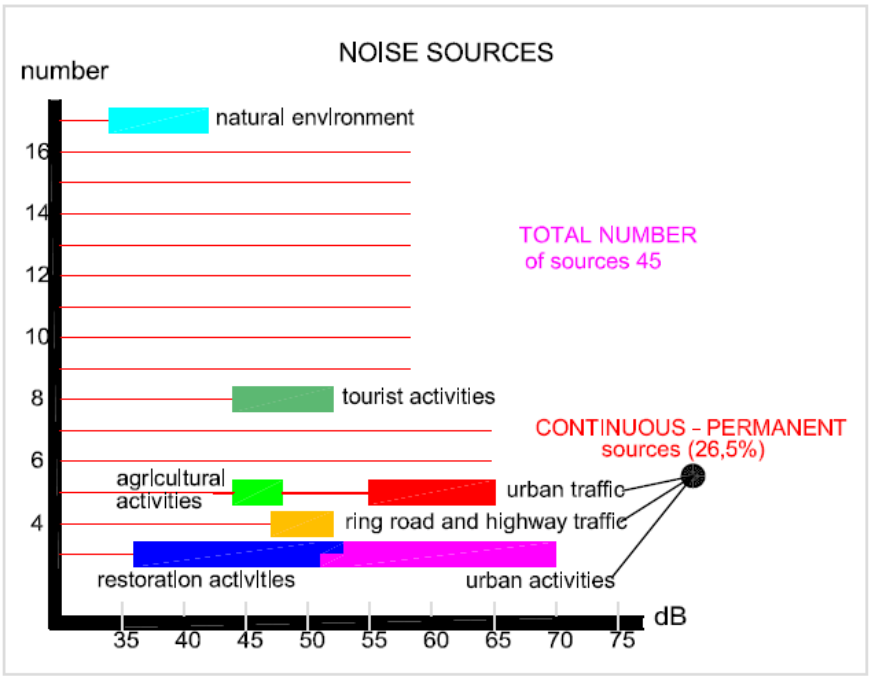

FIGURE 6

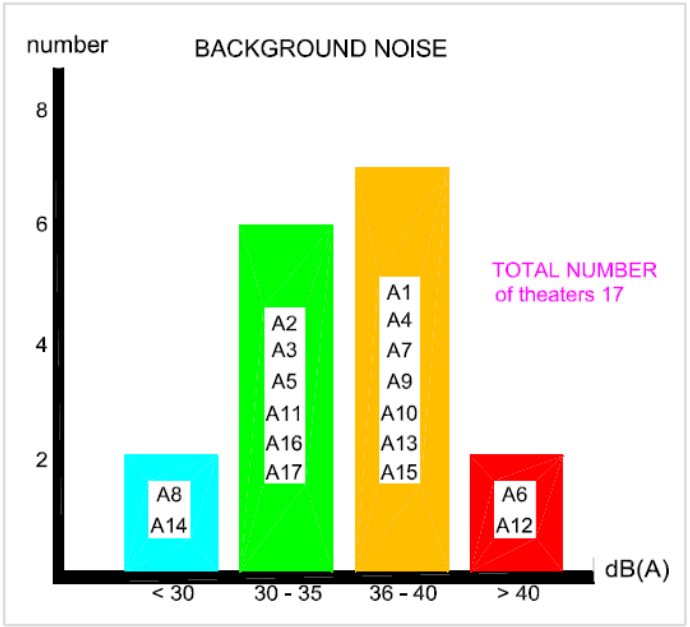

FIGURE 7

Additionally, the values of the undefined back ground noise BN recorded in all the ancient Greek theatres of the sample are shown in **Figure 7** [sound levels in dB, Lmin].
For the acoustic evaluation of the sample, for contemporary performances or for potential future re-opening, we have laid out a numerical model to calculate the effective signal rising (Ra), with the following assumptions [11]:

-the actor is at the back of the orchestra (not in the center, but at the crossing point of the possible scenery with the central axis of the *koilon*), human sound source is 1,7m above the level of the orchestra,

-the initial intensity **Lo** (the human voice of an experienced actor) is 87dB [A] / at 1m, with spherical wave conditions (without any electrical reinforcement),

-the audience is at a maximum distance of approximately 40m from the actor (i.e. in lateral or central positions corresponding to min 90% of the seats, except for the third *diazoma*), level 1,1m above the corresponding gradients,

-the decrease of the direct sound **Ld** (due to the distance) is 32dB [A],

-the natural (passive) loudspeaker amplification of the theatre space **Frp** is +3 dB (grace to the perfect reflector of the orchestra, material covering without sound absorption),

-any background noise **Nbn** is amplified +5 dB due to the presence of the crowd during the performance,

-the rising **Ra** of the effective signal is min 20dB,

-the final rising signal values are given in global decibel values according to the formula:

$$\mathbf{Ra = Lo - Ld + \{ Fpr \} - \{ Nbn + 5\} \geq 20\ dB}$$

As shown in **Figure 8**, the ancient Greek theatres of the sample are classified, relatively to the limit of the yellow line, as follows:

-two (2) in exceptional acoustic conditions (Ra > 20dB): Dodoni, Epidaurus (natural environment),

-five (5) in good conditions (Ra ≈ 20dB): Amphiaraion at Oropos, Thassos, Maroneia, Thorikos, Delphi, (semi-urban environment with occasional rural or tourist activities)

-seven (7) in moderate acceptable conditions (Ra ≥ 15dB): Messini, Eretria, Argos, Dion, Megalopolis, Mantineia, Philippi (semi-urban environment with rural activities or traffic)

-three (3) in non-acceptable conditions (Ra < 15dB) Orchomenos of Beoetia, Larissa and Athens Dionysus (urban or semi-urban environment and traffic).

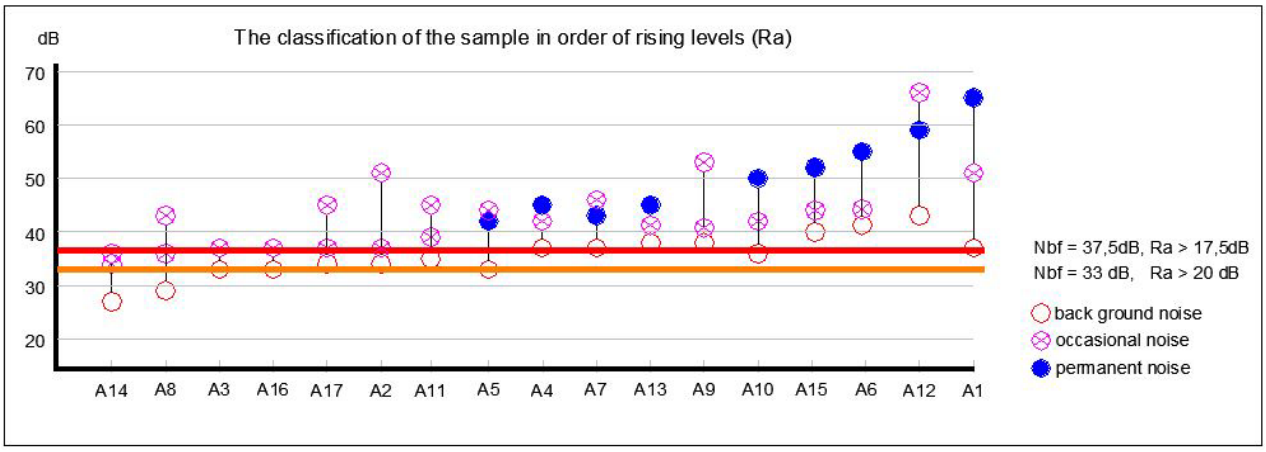

Figure 8. The calculation of the sample for limited acoustic conditions. In empty red circle the background noise, in red circle with X index the occasional noise and in dark blue circle the permanent sound nuisance (traffic, urban activities).

Alternatively, for limited acoustic comfort conditions and provided the presence of a movable scenery depth during the performances, the calculation model was converted as follows:

-the natural (passive) loudspeaker amplification of the theatre space **Frp** is min +5dB (grace to the positive early reflections for the orchestra, the scenery and their combination),

-the acceptable rising of the effective signal **Ra** is limited to min 17,5 dB, according to the formula

$$\mathbf{Ra = Lo - Ld + \{ Fpr \} - \{ Nbn + 5\} \geq 17,5\ dB}$$

As expected, the classification of most theatres of the sample was improved, relatively to the limit of the red line in **Figure 8**, as follows:

-Thirteen (13) between acceptable or exceptional acoustic conditions (Ra ≈ 17,5 > 15dB): Dodoni, Epidaurus, Amphiaraeion at Oropoy, Thassos, Maroneia Thorikos, Delphi, Messini, Eretria, Argos, Dion. Megalopolis, Mantineia (natural or semi-urban environment with occasional rural / tourist activities)

-four (4) in unacceptable conditions (Ra << 17,5 dB): Philippi, Orchomenos of Boeotia, Athens Dionysus and Larissa (urban or semi-urban environment, with activities and traffic).

4. Conclusions

The systematic recording of the existing conditions in the theatrical monuments of the Antiquity enables the clear identification of their potential reuse for contemporary performances. The acoustic monitoring of their surrounding environment provides the ability to predict the intelligibility of the theatrical message.

The most important problem is the generalized destruction of the stage buildings. This ending, as discussed in previous paper, imposes the presence of a movable, low and lean scenery depth (a mobile stage background in the correct position and of a suitable size used during a performance), which could contribute mainly as an active sound reflector (+2 or +3,5dB supplement to useful signal), and secondly as a small noise barrier (-1 or -3dB beneath environmental noise) on the exposed part of the open floor plan of the ancient Greek theatre [2], [6]. Such an intervention could improve the acoustic quality to six out of the seventeen theatres (35%), ensuring well accepted acoustic comfort at thirteen out of the seventeen theatres (76%) of the total sample.

The above estimation is rather conservative, because the usual absence of a scenery depth in contemporary performances obliges the actors to move towards the cavity in an attempt to compensate sound loss. As a result, the main sound reflector of the orchestra is, also, cancelled.

Furthermore, as regards the environmental noise, during our research we identified and recorded intense urban pressure, mainly traffic noise, which exercises serious nuisance (51-70dB) in the acoustic environment of the theatrical monuments. The geometrical sizes of the ancient Greek theatres and their potential function for natural (passive) loudspeaker amplification, combined with physiological, voice and audio data of a theatrical performance do not allow the proper theatrical function under distinct nuisance conditions (>35dB).

This sound limit coincides with the international standards for enforced silence in cultural sites (noise criteria NC - 25) and specifies the responsibility of the Greek authorities to finally enact a silence criterion concerning the theatrical monument area, to impose obligatory measures regarding noise protection (from urban or traffic activities) and to adopt temporary or occasional arrangements in the region until the final removal of permanent noise sources.

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