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*Diagnostics for Cultural Heritage:*

# ANALYTICAL APPROACH FOR AN EFFECTIVE CONSERVATION

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**VOLUME DEGLI ATTI DEL WORKSHOP**

# "DIAGNOSTICS FOR CULTURAL HERITAGE: ANALYTICAL APPROACH FOR AN EFFECTIVE CONSERVATION"

*Palermo – 10 Giugno 2013*

*S. Antonio Abate – Complesso dello Steri*

Piazza Marina 61, Palermo

**A cura di:**
**Maria Brai, Luigi Tranchina, Maria Alberghina,**
**Dorotea Fontana, Federica Fernandez**

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# DIAGNOSTICS FOR CULTURAL HERITAGE: ANALYTICAL APPROACH FOR AN EFFECTIVE CONSERVATION

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# PREFAZIONE

BRAI M

*Questo volume raccoglie i contributi degli Autori che hanno preso parte al primo workshop: Diagnostics for Cultural Heritage: Analytical Approach For An Effective Conservation, tenutosi a Palermo il 10 giugno 2013, nella splendida cornice della Cappella di S. Antonio Abate, all'interno del complesso monumentale di Palazzo Chiaramonte Steri.*

*In questa raccolta viene posta in evidenza la necessità di un approccio scientifico interdisciplinare e vengono ben focalizzate le competenze scientifiche integrate nell'intento di affrontare i diversi aspetti degli interventi di conservazione e di fruizione dei Beni Culturali.*

*Lo studio accurato del Bene Culturale diviene, infatti, esso stesso documento storico, ed indubbiamente risulta essere uno strumento indispensabile per la prevenzione del degrado, per l'ottimizzazione degli interventi di restauro e per la scelta dei protocolli di conservazione.*

*Il workshop Diagnostics for Cultural Heritage: Analytical Approach For An Effective Conservation, è stato quindi rivolto alle tecniche fisiche, chimiche, biologiche, geologiche, applicate sia ai materiali costituenti i Beni Culturali sia ai materiali innovativi ideati per le procedure di restauro e conservazione degli stessi.*

*Il workshop che ha visto la partecipazione di illustri esponenti Internazionali e Nazionali nell'ambito delle tematiche trattate, è stato anche un'occasione per la presentazione di alcuni dei risultati ottenuti da studenti del Master di II Livello "Ricercatore Esperto di Nanotecnologie e Nanomateriali per i Beni Culturali" durante lo svolgimento delle attività di tesi sperimentale.*

*Il volume vuole essere una testimonianza dei risultati esposti dai partecipanti in questa, spero ripetibile, occasione.*

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# A STUDY OF THE ACOUSTIC PARAMETERS OF ANCIENT THEATERS

Rodonò G
Franzitta V

## INTRODUCTION

Although many centuries have passed, in many ancient theatres evocative theatrical performances still take place, especially during summer. Greek and Latin architects care for equilibrium of proportions offers not only an intense quality of view but also a high quality acoustics. In our study we did an analysis both theoretical and experimental of the acoustic parameters of the ancient theaters of Syracuse, Segesta, and Akrai, in Sicily and the theater of Bulla Regia, in Jendouba (Tunisia), it was only simulated, because of the inability to reach the scene for reasons due to the political turmoil.

A measurement session was carried out by our team in the framework of a wide research project on ancient theatres acoustics in the modern use. From data recorded "room criteria" parameters have been evaluated together with spectral analysis in order to gain deeper information on the acoustic field. Main results are compared to data collected during the team experience in the past years.

## CASE STUDY:

### 1. SYRACUSE THEATRE

The ancient theatre in Syracuse is a greek-roman type. The orchestra is an semicircle with a 29 meters diameter and the stage (scena) is not preserved. The cavea extends for 180° around the orchestra and continues with two wings for about 5 m at the sides. It is radially split in nine sectors, kerkìdes, by eight stairs, klimàkes, 0.6 m large: rougly each stair counts two steps every cavea step. First twelve cavea steps, from the bottom, constitute the *ima cavea* which has an average slope of 22,5°. This area is bounded on the upper part by a step 0.86 meters high, after which rows slope is about 20,8°. This area, media cavea, is bounded on the upper part by a large passage, *diàzoma*. Further on this passage up to the last row we have the *summa cavea*, with the same average slope of the *media cavea*. Most of the summa cavea is absent today and the grass appears after few rows. During the drama festival most of the cavea is covered by wood planks hiding the stone below while there were two kind of stage.

### 1.1 ACOUSTIC MEASURES

Measurements were carried out along a day [1], [5]. Several source-microphone couples were characterized using pink noise interrupted excitation and MLS based impulse response (IR) measurements in unoccupied state. Only few source-microphone couples were tested in a

partially occupied state (about 15 %).The theater acoustic was studied using main room criteria.

Figure 1. Syracuse ancient theatre plan and photo

This is justified by fact that a small reverberant field exists and a rough linear SPL decay occurs. In Fig. 2 a Syracuse and Segesta theaters RT values are plotted (source on the stage – average of three microphone position along the central sector for both theaters). These large differences are due to the presence of the stage but others indices, as EDT, $C_{80}$ and $D_{50}$, here not reported, do not differ at all.

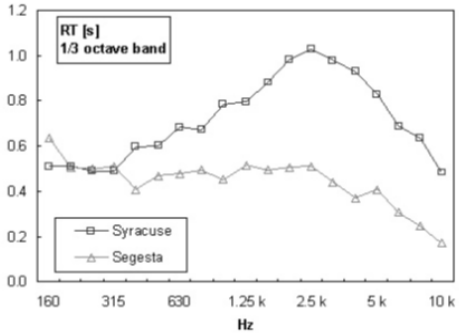



Figure 2. Comparison of Syracuse and Segesta theaters RT values

## 2. BULLA REGIA THEATRE

The theater is almost perfectly oriented to the north (the axis is deflected about 18° to the NW), the orchestra has the diameter of about 20 m; the cavea has a diameter of about 52 m and a slope of about 39°. The auditorium is built on a flat plot with the slope created artificially, usually used to do as the

Romans, it has the shape of a semicircle is not complete and is made up of 6 to 8 wedges and stairs. The three steps closer to the orchestra, reserved to the authorities, are delimited by a low wall of separation from the rest of the auditorium and have a slope of about 16.7°.

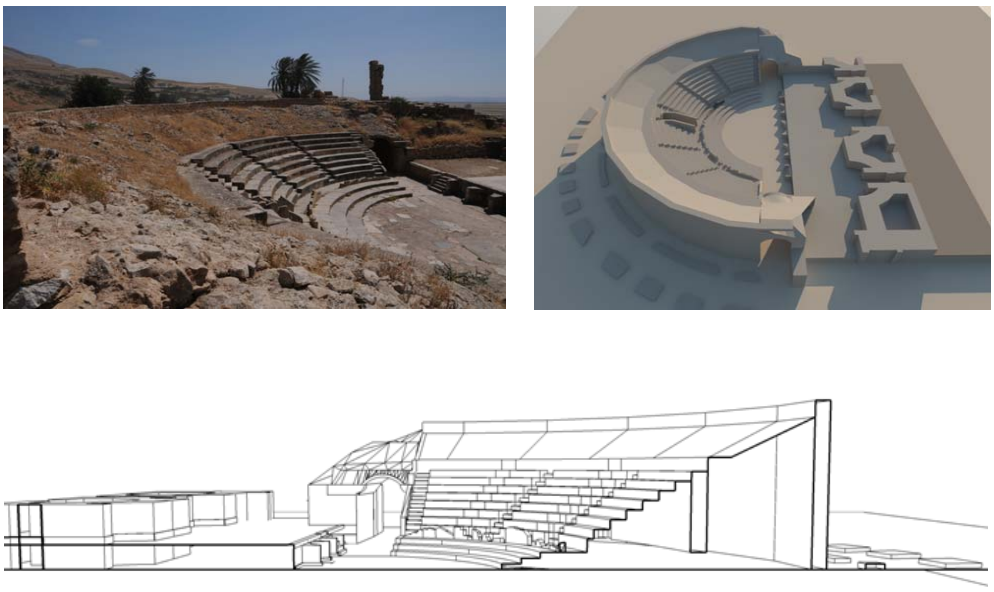


Figure 3. Bulla Regia ancient theatre plan and photo

## 2.1 ACOUSTIC SIMULATION

The software used for the acoustic simulation is "Odeon Program" ver. 10, developed by Christensen.

After constructing the model of the theater in its current configuration [7], it was desired to deepen, the acoustic parameters (Lp - STI - $D_{50}$) for configurations that were deemed the most interesting in the use of the theater.

In particular, it was considered the conduct of the theater:

- in the presence of the public and in the event of an extension of the auditorium;
- With scenes and backdrops of different forms and with different coating materials having an average absorption coefficient.

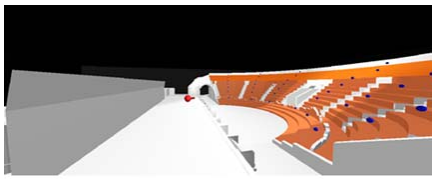


Figure 4. Odeon Simulation

The graphs of Fig. 5 show, for the acoustic parameters (EDT, $T_{30}$, SPL, $C_{80}$, $D_{50}$) averaged values between all points microphone, in function of the frequency (1 octave), for each position of the sound source (A, B, C, D, E) of the scheme showed in fig.4. [7]

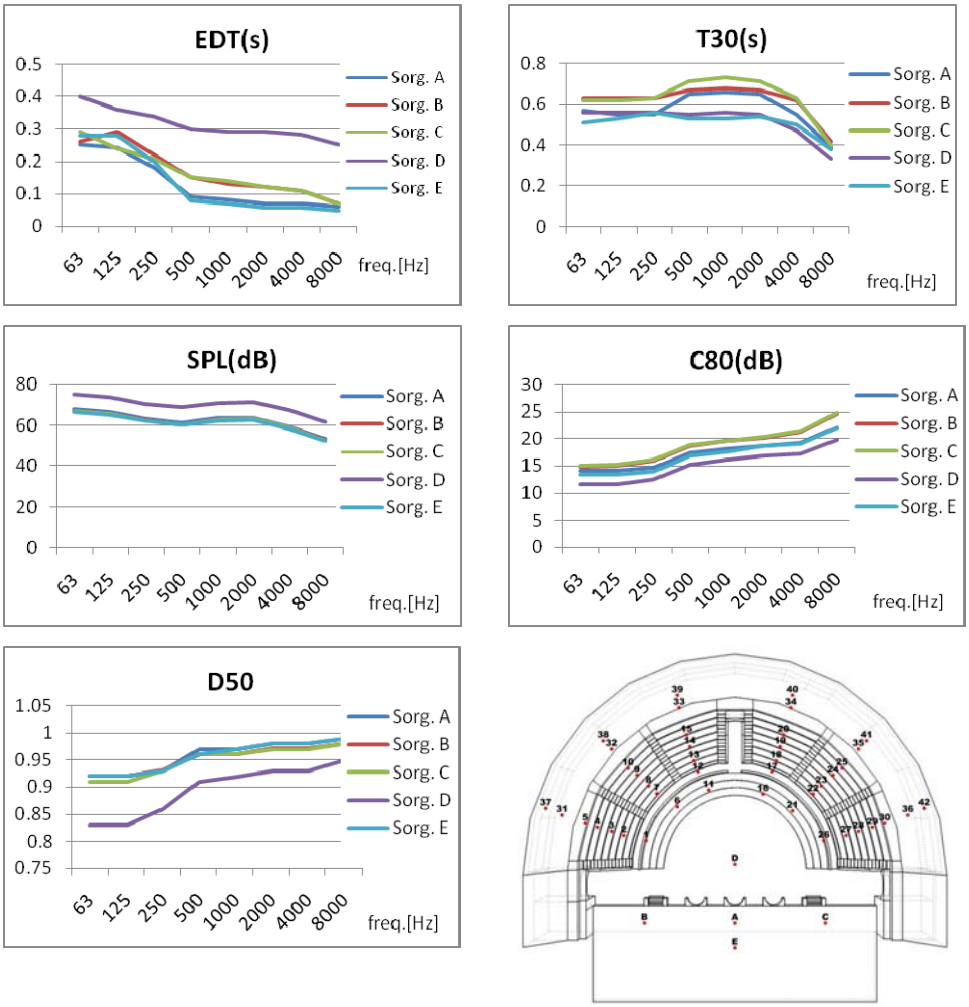



Figure5. Averaged values of all the points

3. SEGESTA THEATRE

The theatre is placed inside the archaeological site of Segesta, in the North of the acropolis. Built with solid tufa blocks, its structure presents the geometry and the proportions typical of the ancient Greek theatres, described in V book of Vitruvio's treatise "De Architectura" as the construction method of the three squares. The cavea diameter is of about 63 m with a slope of 26.57°. The semicircular orchestra, is actually without floor and its diameter is about 16.51m.

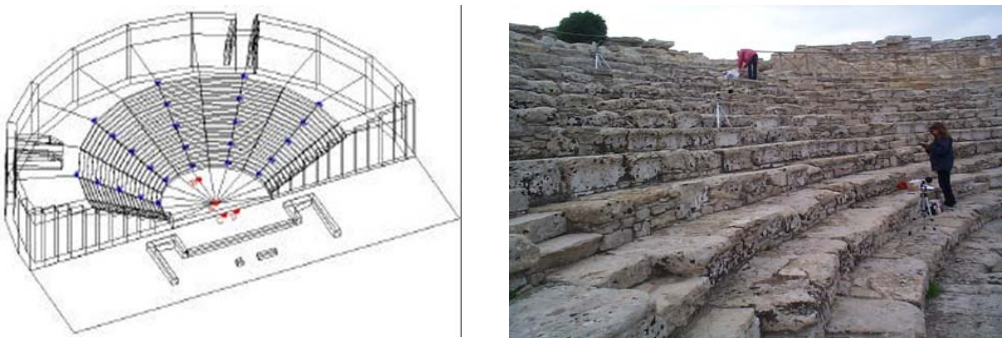


Figure 6. Segesta ancient theatre plan and photo

### 3.1 ACOUSTIC MEASURES AND SIMULATION

The sound source (a dummy pistol) has been placed in 4 points of the theatre. The condenser equipped microphones have been set at a height of 0.8 m above the respective gradine. Starting from the central sector, the microphones position changes with clock wise rotation. For each microphone setup the source has been placed in 4 different points [2], [4] and three measurements have been carried out for every source position, in order to execute a statistical average. In total 36 measurements have been carried out.

In Fig. 7, we are going to consider impulsive response for the microphone 1 with the source in A position (centre of the orchestra).

The relative decay has been executed by means of the backward integration method of the square impulsive response by Schroeder (see Fig. 8).

Reverberation times analysis shows values of about 0.4 s (see Fig. 9). Other reverberation times with values greater than 0.4 s have been observed, especially at low frequency and in the upper positions. This issue will be the subject of further research. By the studying of Vitruvius treatise, "De Architectura", the comprehension of geometrical methods and proportions used to plan the theatre was made possible; with the help of surveys a graphic reconstruction of the theatre was made in order to use it in the predictive ray tracing software Epidaure. Predictions have been obtained using two kinds of sound source that has been placed in 4 different positions of the orchestra:

- Directional: shouted human voice, simulated in accordance with the directional parameters of Dunnand Funnsworth study;
- Omnidirectional: white or pink noise emission.

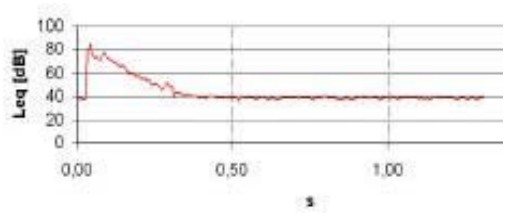



Figure 7. Statistical average of three shots impulsive response; source in A position, microphone 1, 1kHz centered third octave band

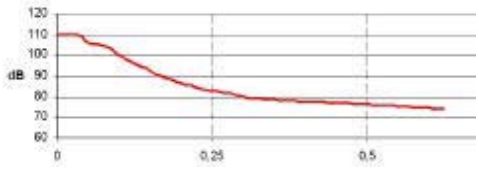



Figure 8. Sound decay, microphone 1, source in A position

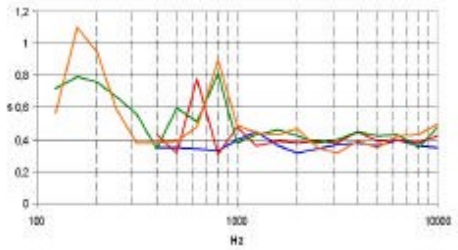



Figure 9. Reverberation times ($T_{15}$) source in A position: microphones 1(blu line), 2(red line), 3(green line), 4(yellow line)

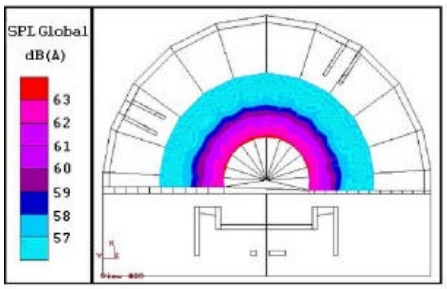



Figure 10. SPL global. The theatre is empty and the source in A

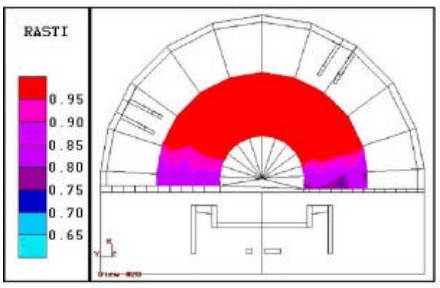



Figure 11. RASTI map. The theatre is empty and the source in A

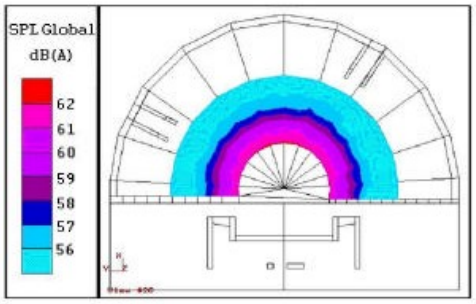



Figure 12. SPL global. The theatre is full and the source in A

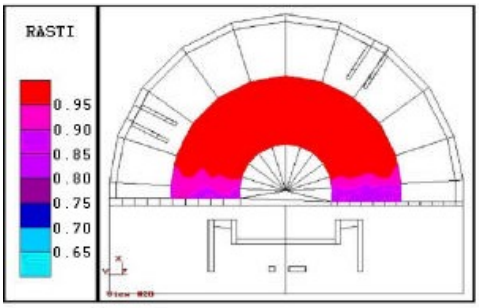



Figure 13. RASTI map. The theatre is full and the source in A

In the centre of the orchestra, A position, there was an altar consecrated to Dionysus (timele), that is an important place from the acoustical point of view. In facts all the cavea steps are like cylindrical mirrors (axis in A) and during a speech it is possible to listen to a very good reverberation effect that emphasizes the speaker's voice.

SPL maps analysis shows that sound field variation, related to the presence of the spectators, depends on the contribution due to reflections.

The RASTI index shows very good values (> 0.75) in both cases.

## 4. AKRAI THEATRE

The theater of Akrai, built in the third century BC, is located near Palazzolo Acreide at an altitude of 770 m. It's almost perfectly oriented to the north (the axis is deviated by 8.8° towards NE), facing Mount Etna and Anapo valley. The theater, partly on a natural slope, originally had a perfectly semi-circular and consisted of 9 wedges and 8 scales. Has a slope of about 24° and has a diameter of about 42 m, while the diameter of the orchestra is about 21 m (20.9 m).

### 4.1 - ACOUSTIC MEASURES AND SIMULATION

Several measurements were made of the sound response [6], in order to characterize the acoustic parameters of the theater in the following situations:

• steady-state, • transient switching off the stationary source, • transient with the impulse response, • different pairs source-microphone.

The measurements were carried out in the absence of the public, and without any empty theater scene mounted.

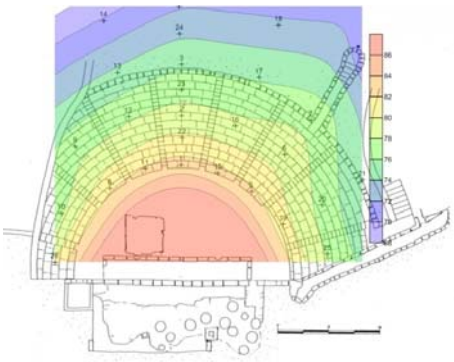
Three positions were chosen for the source and 26 microphone positions.

The positions of the sources were chosen to simulate those likely than an actor playing at the level of the orchestra and an actor playing out a scene at a height of 80 cm.

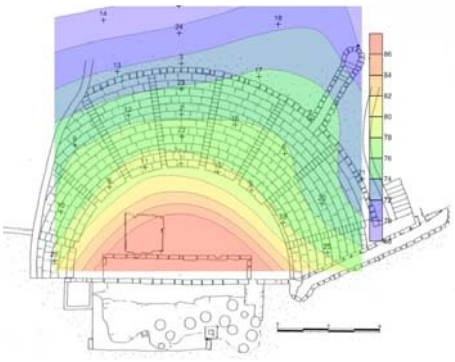
Figure14 shows the sound pressure level Lp (A), in the form of iso-chromatic map obtained by interpolation of the experimental data. The maps of the sound level have good symmetry on the auditorium even when the source is slightly off-center.

Also in this theater the software used is Odeon.

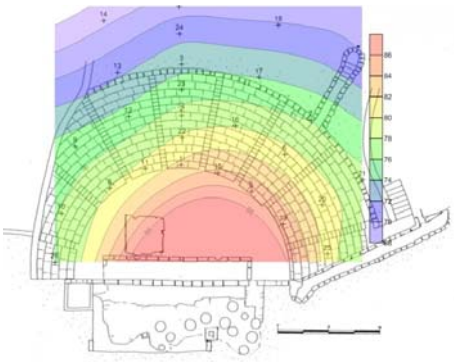
To make predictive simulations of the acoustic parameters was first created a graphical representation (model) of the theater in which the three-dimensional surfaces reproduced in the model are the relevant ones from the acoustic point of view: each surface is characterized by its sound absorption coefficients of the materials of which is actually made.



Source in A



Source in B



Source in C

Figure 14. Noise levels maps Lp (A)

After constructing the model of the theater in its current configuration, it has been validated progressively refining the acoustic data and geometric as long as the data obtained experimentally were not reasonably overlapped with those obtained from the simulation . Once you have verified that the model was fully reliable values are derived by means of simulations and for configurations that are desired depth , the acoustic parameters of qualification (Lp - STI - $D_{50}$).

In particular, it was considered the following situations of the theater :

- Conditions in the absence and presence of the public;
- With scenes and backdrops of shapes and with different coating materials having absorption coefficients of the medium;
- In the case of an extension of the auditorium to increase the presence of the public.

In Figs. 15 are compared the measured data and the values obtained from simulation in the current state and in the absence of the public.

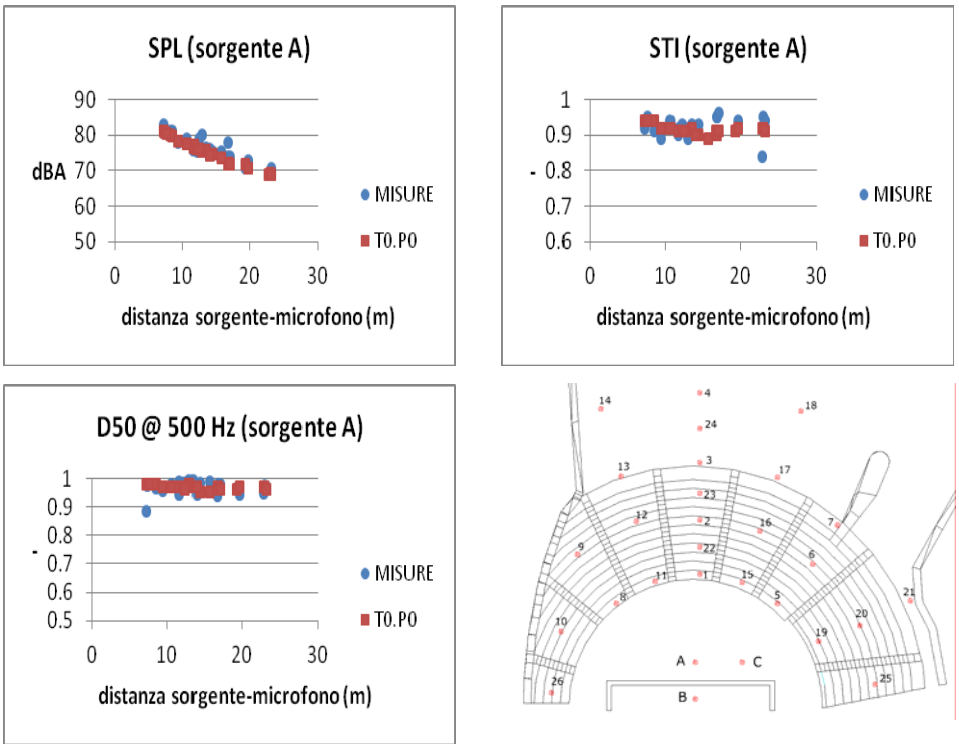



Figure 15. Comparison of data measured with data obtained from simulation

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