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The Acoustic of Cumaean Sibyl

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The Cumaean Sibyl cave is a mythological place in the north of Naples, where the Sibyl, a priestess presiding over the Apollonian oracle, received the travellers and predicted their future. The cave is length about 140 m, with trapezoidal section excavated in the rock of tuff. The cave has a height of about 4.5 m and it is 2.4 m wide. The legend says that the Sibyl received the travellers in the final part of the cave. Acoustic measurements were done with an omnidirectional sound source in the in the room inside the Sybil cave while positioning the microphones along the cave. An architectural acoustic software was then used to better understand the sound propagation in the cave. From acoustic measurement and numerical simulation results show that the voice emitted by an orator, positioned in the room inside the Sybil cave, is correctly understood in every point of this long tunnel. This shows that the legend that this site was used for by an oracle may have a scientific truth basis.



1. INTRODUCTION

The science of sound has always fascinated mankind since ancient times [1]. Primitive men did not know the phenomenology of sound propagation and they associated unexpected sounds such as echo to the presence of spirits or to the voices of the dead [2-5]. Over the centuries, the sound accompanied the religious rituals. In the antiquity, the role of religious observers in the movements of the stars and natural phenomena such as leaf picking, thunder, or flight of birds often was used to predict the future and to regulate various human activities. In this context, many researchers believe that the shamans were the first experts of the science of sound because they used sound effects and those environments with amplified sounds, as a source of mystery. It is for these reasons that most of the time, the rites were celebrated inside large spaces such as caves, whose reflective walls amplified sounds. In the ancient period, many religious rites were accompanied by rhythmic music performed by drums, again to increase an emotional participation.

Recent studies have shown that pre-Columbian societies of Central America believed that the echoes were the voices of the spirits. The pyramid of Castillo, in the Yucatan Peninsula (Mexico), with its 91 steps each, allows to hear a sound similar to the rain while going up, while clapping at the foot of the stairs, it is possible to hear a sound similar to a quetzal, a sacred bird for the Maya [6, 7]. In Syracuse (Italy), the cavity known as "Ear of Dionisio" is famous for its echo; according to the legend, the tyrant Dionysius (V century B.C.) could listen, hidden at a point in the top part of the cave, the voices of prisoners to snatch their secrets [8]. In ancient Greece, famous sites were used by oracles, as in them the voices of the gods could manifest in answering travelers' questions. In the oracles, priest or priestesses who conducted oracular interpretation lived. These were considered the source of wise recommendations, through sounds from rustling leaves or from the rumble of thunder and predicted the future of the travelers. For example, the oracles were consulted by the kings and soldiers before military expeditions, and in the wars between Sparta and Athens, the oracle of Delphi played an important role. The oracle was a priest or a priestess who lived in a temple or cavern.

The purpose of this paper is to investigate the acoustics of a famous ancient site, making measurements with modern acoustic techniques and rebuilding the sound field of the original place through a virtual model. Applying this approach, it was possible to rebuild the sound field of a place that was used for rituals or sacred functions. The cave called "the Cumaean Sibyl", while not a natural cave, and has aroused the interest of the authors due to the legend that travelers used to go to the Sibyl to receive prophecies.

2. THE SIBYL

The Sybil, who is the woman that can predict the future, is present in the tradition of several countries. Some populations of Western Asia were handed down in the form of verses the oracular responses of prophetesses known as Sibyls. A legend tells about a foretelling lived near Troy, known for having expressed his oracles in riddles written on the leaves of plants. The Sibyl, in the Greek and Roman mythology, was a woman with divine powers that had been donated by Apollo. The Sibyls lived in caves or near waterways and foreteller in a state of unconscious delirium. The Sybil lends her voice to the oracular god in the grip of suffering. The myth of the Cuman Sybil has passed through millennia always preserving the charm of primitive superstition from which it originates adapting to ethnic and cultural.

Since pre-Homeric era, the myth of the Sybil came unchanged in its meaning until the Middle Ages and its memory still lives today in the works of writers and artists. Cuma, an ancient town in Campania (Italy), in the north-west of Lake Averno, used to be Greek colony located, in a zone of volcanic activity, the "Campi Flegrei", that was favorite during Roman times for its thermal waters. In this town, the cave of the Sybil is a famous tunnel dug into the tuff. Virgil describes this cave, in Book IV of the Aeneid, identifying as the abode of the priestess of Apollo [9]. Some scientists believe that the cave could be a rare example of funerary architecture inspired by the Cretan-Mycenaean, although recent studies attribute to the structure a defensive function, according to which this work is part of the larger project of strategic strengthening of the "Flegrei" ports entrusted by the Roman Emperor Agrippa to the architect *Cocceio*. However, at the same time, it recovers its sacred function, since the town of Cuma was devoted to the family of Augustus. The cave consists of an underground straight tunnel, 140 m long, with a trapezoidal

regular section with an average width of 2.4 m and about 4.5 m high [10]. The site currently lacks the original entrance that collapsed (Fig. 1).

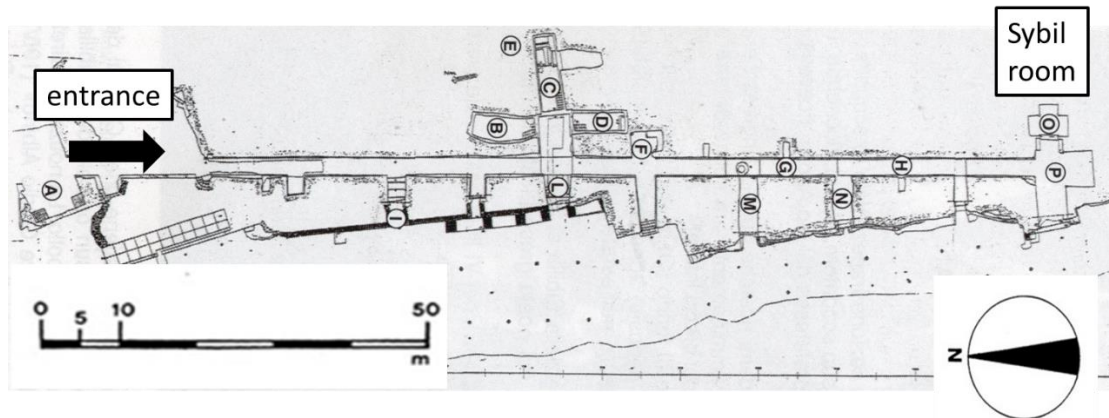


Figure 1. Plan of the Sibyl cave.

The outer side is defined by six large trapezoidal fissures, which light the tunnel. On the eastern side, another gallery opens with three rectangular rooms arranged in a cross which constitute tanks supplied by a channel in which the Sibyl washed and then wearing a long dress went into the inner room, where she prophesied from a high throne. At the end of the gallery, a high rectangular room with three large niches is located and, with a vestibule on the left side closed by a railing that leads into a small room divided into three smaller cells. This is the oracular room, the place where the Sibyl declared her predictions.

Figure 1 shows the plan of the Sibyl cave. The path is uneven on the floor, lightly sloped with a drop towards the terminal represented by a vestibule containing a pair of seats carved into the rock, and beyond them a vaulted room. Perhaps visitors of the Sibyl were seated waiting to consult her while she prophesied hidden from the door that originally separated the vestibule from inner temple. Figure 2 shows the section of the Sibyl cave, in the entrance area.



Figure 2 - Section of the Sibyl cave (entrance area).

Those who went to the Cumaean Sibyl seeking advice were introduced to the vestibule in front of the inner chamber of the oracle, through a gallery in which light and shadow alternated. This alternation meant that anyone who came inside to lead newcomers to the temple appeared and disappeared intimidating visitors and creating that particular effect described by Virgil: “The enormous side of the Euboean cliff opens in a cave: led them one hundred large steps, one hundred doors; from there, many voices erupt the responses of the Sibyl”. During the imperial first century, the official cult of the Cumaean Sibyl ceased and the cave was used as a cemetery for Christians. However, the memory of the ancient rite still persisted in the fourth century A.D., although the cave received several transformations over the centuries.

The first two sections of the tunnel, the first 17 m long is opened and without walls and the second 15 m long is only open, are missing the roof while the remaining part of the cave is well preserved. The cave was unearthed in 1932 by the archaeologist Amedeo Maiuri, who, after six years of excavations, came to the discovery of the corridor "high and solemn as a temple" described by Virgil in the Aeneid (Fig. 2).

3. ACOUSTIC MEASUREMENTS

The acoustic measurements were carried out with an omnidirectional sound source located on the altar and with 12 microphone points placed in different positions in the area occupied by the listeners, in accordance with the ISO 3382 [11]. The impulse responses were detected with a measurement microphone GRAS 40 AR endowed with a preamplifier 01 dB PRE 12 H. The sound source was powered with a MLS signal, the elaboration of impulse responses was realized with the software Dirac 4.0. During the acoustic measurements, the background noise was lower than 30 dBA, and the cave was empty. Figure 3 shows the plan of the cave with the indication of the position of the sound source and of the microphones. Figure 4 shows the sound source during the acoustic measurements. The sound source was placed at a height of 1.6 m from the floor and the microphone at a height of 1.3 m in the area occupied by the listeners.

The analyzed acoustic parameters were T30, EDT, D50, and C80. These parameters were measured in the room in which it is assumed the Sibyl lived, both along the straight corridor leading outside or along the path that travelers carried out to enter the cave of the Sibyl. In addition, the sound level was measured at different distances from the source position to the outside, along the straight corridor to enter the cave. Figure 5 shows the sound source and microphone positions during the acoustic measurements.

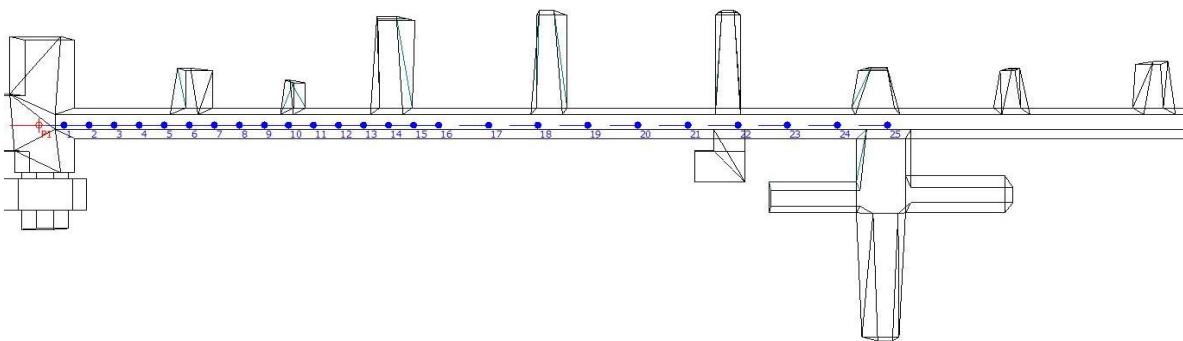


Figure 3. Plant of the Sibyl cave with the position of measurements points



Figure 4. Sound source in the Sibyl cave during the acoustic measurements.



Figure 5. Sound source and microphone in the room in which lived the Sibyl.

4. RESULTS

Figure 6 shows the average values of the acoustic parameters in the octave band from 125 Hz to 4 kHz, obtained as average values of the acoustic parameters measured at various points of the cave, Sibyl room and straight entry corridor.

Table 1 shows the sound pressure level, as a function of the distance. The Table shows that for the first meters, the level of the sound pressure remains constant (diffused sound field) and then the sound level begins to decrease. By comparing the values of T30 and EDT, with those of other underground sites, at low frequencies, the measured values in the cave of the Sibyl are higher than those measured in tombs carved into the tuff, as the Catacombs and those measured within karst caves, despite the straight corridor of the cave presents lateral openings to the outside [12, 13].

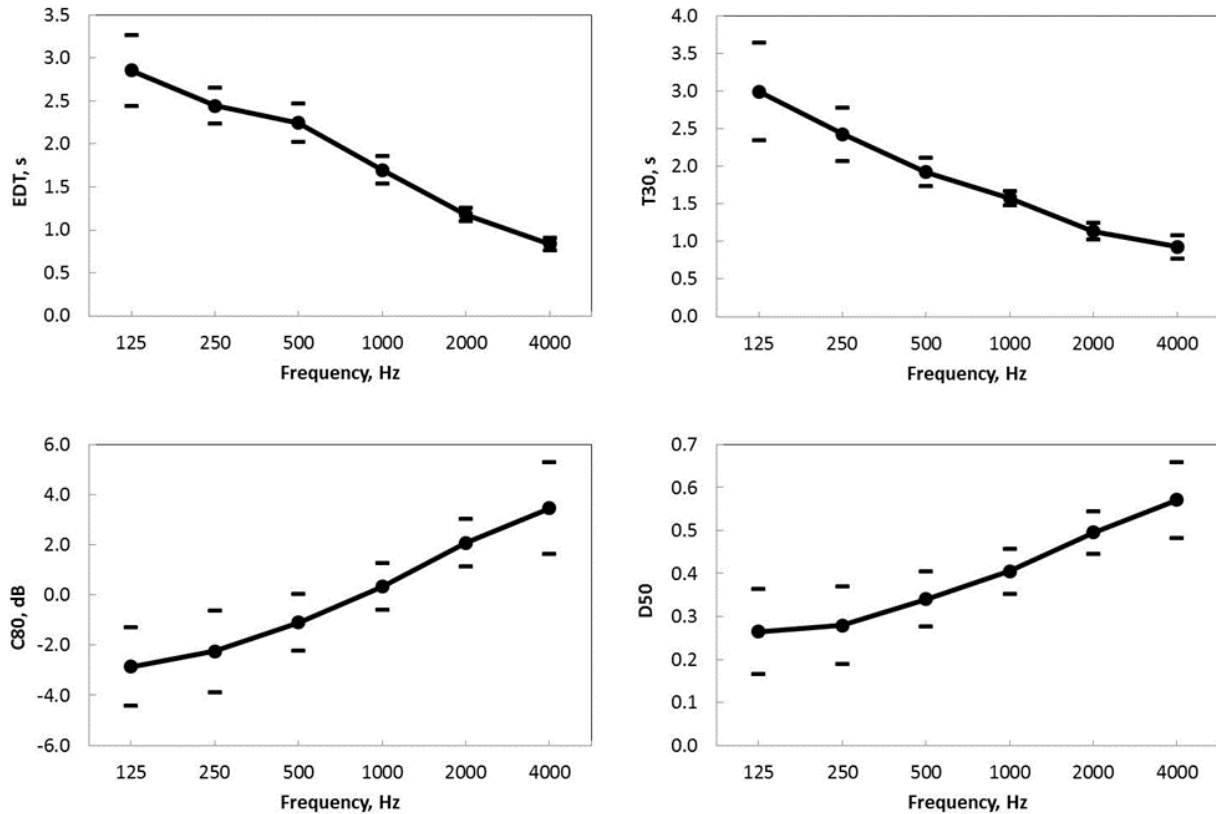


Figure 6. Average values of acoustic parameters measured along the corridor in the Sibyl cave.

At the frequency of 1 kHz, the T30 is about 1.5 seconds, while the D₅₀ is 0.4 and the STI is 0.5. These values denote a good condition for speech listening along the cavern. The dispersion of the measured values, highlighted by the standard deviation only occurs at low frequencies. However, at medium and high frequencies, the standard deviations are negligible for EDT and T30, therefore there is no spatial variation of these parameters, while for D₅₀ and C₈₀ the standard deviation changes even at medium and high frequencies, which means that the spatially measured values differ from point to point.

Table 1. Sound pressure level as a function of the distance from the position of the sound source.

Distance from the source (m)	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
1	75.2	79	76.2	73	73.2	69.2
2	72.1	76.7	72.3	69.8	70.5	65.2
4	70.4	76.5	71.7	68.4	69.7	64.8
5	71.9	74.8	70.8	68	69.3	63.2
6	70.8	74.3	71.0	67.9	68.7	62.9
8	70.2	74.3	71.1	68.4	68.7	62.6
9	71.1	75.0	71.5	67.6	68.6	62.4
10	70.8	75.2	70.9	67.6	67.9	61.9
11	69.2	73.6	70.7	67.2	66.9	60.7
12	68.6	71.9	68.8	65	65.2	59.8
13	67.3	71.3	67.5	63.9	64.9	58.7
14	67.6	69.8	66	62.6	63.6	57.2
15	65.8	69.8	65.7	62.5	63.2	56.7
16	66.8	70.2	65.3	61.9	63.5	56.8
17	66.0	69.2	66.2	61.6	62.9	56.3
18	66.8	70.2	65.8	61.4	62.0	55
19	66.8	68.7	66.2	61.2	62.0	55.1
20	65.2	69.1	65.4	61.4	61.6	55.4
25	63.9	67.3	63.2	59.9	59.2	52.0
30	63	66.1	62.2	57.4	56.9	49.1

5. VIRTUAL MODEL

To evaluate the acoustic characteristics of the cavern, the architectural acoustics software "Odeon" was used [14, 15]. Odeon adopts a hybrid method of images approach plus ray-tracing. Early reflections are generated by point sources for which the reflection order is less than or equal to the Transition Order (TO). The early reflections take into account the scattering properties of the surfaces. Every time a ray is reflected at a surface, the position of an image source is found.

Usually, a software simulation requires a first step aimed at the development of a model of the space for which acoustic measurements are available. A second step consisted of the comparison of measured quantities with analogous calculated quantities. Figure 7 shows the 3D virtual model of the cave of the Sybil, the acoustic model calibration is made by setting the absorbent coefficient values for all virtual model surfaces and the scattering coefficients until, at each octave band frequencies, the values of reverberation time (T30) calculated and measured were considered close enough (differences below 10%) and the model was validated.

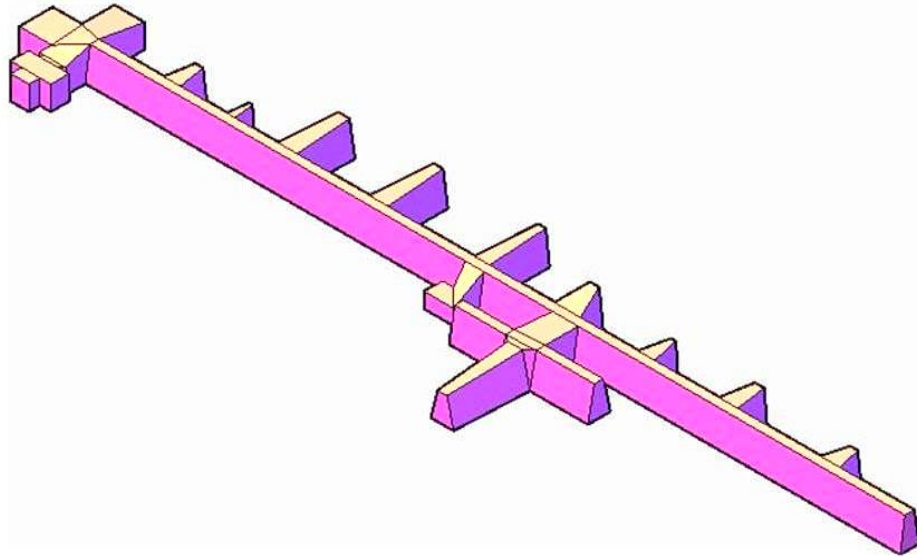


Figure 7. 3D virtual model of the cave of the Sybil.

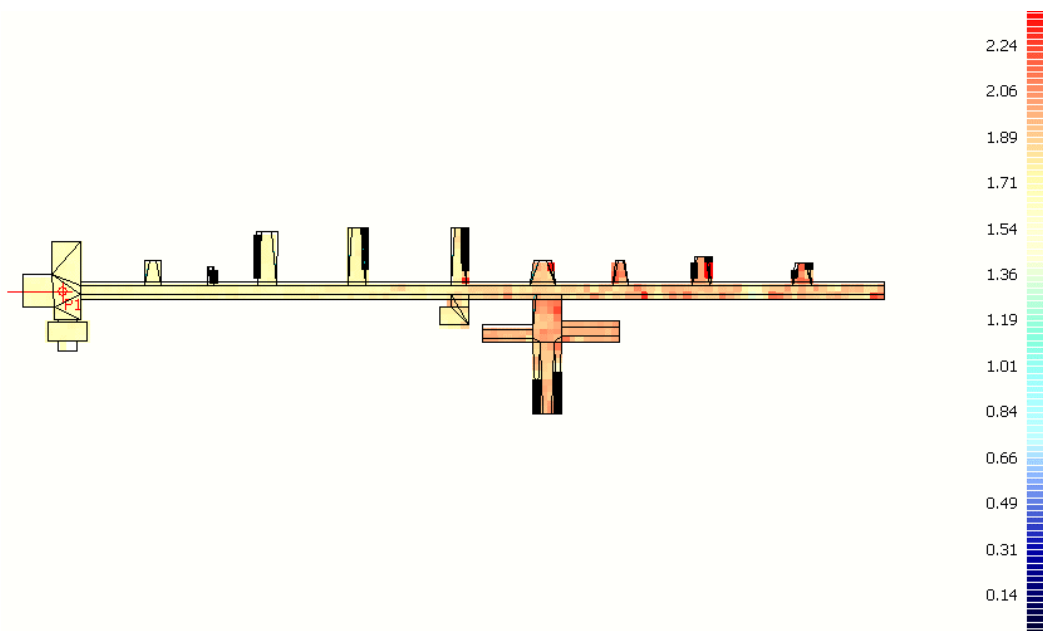


Figure 8. T30 spatial distribution

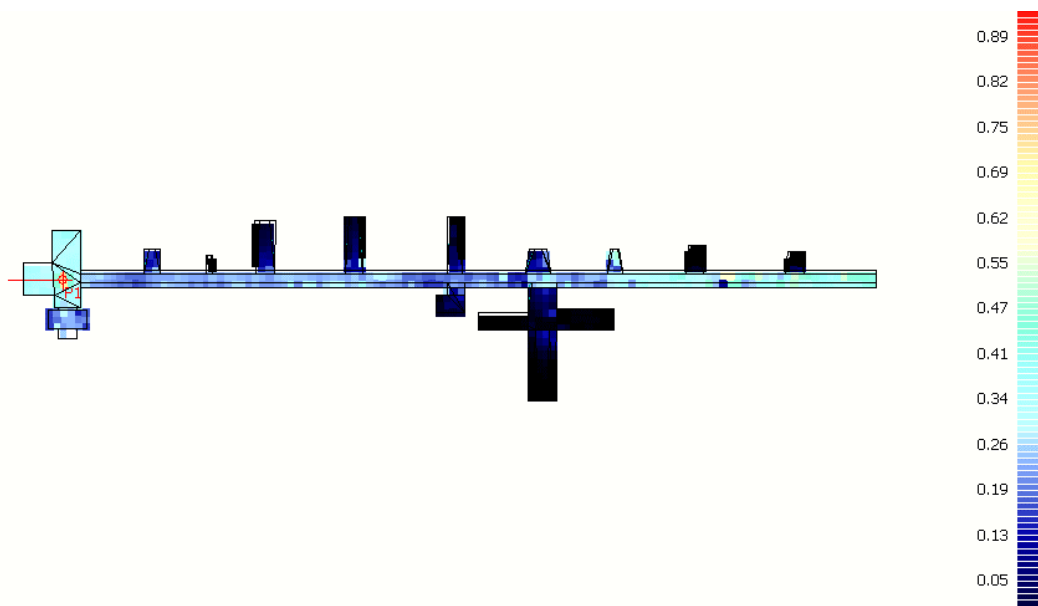


Figure 9. D50 spatial distribution

6. DISCUSSION

The parameters T30 and D50 at the frequency of 1.0 kHz, were chosen for assessing the speech intelligibility. Moreover, the maps of spatial distributions of these parameters were obtained through the virtual model, using the software Odeon. Figures 8 and 9 show the spatial distribution of T30 and D50 respectively. By analyzing the maps and the average values of the acoustic parameters measured, in the situation where the sound source is placed in the Sybil room, opposite to the entrance of the cave, it follows that at the frequency of 1 kHz, the T30 is about 1.5 seconds, and the D50 is equal to 0.4.

From these values, it is clear that a listener walking down the aisle cannot adequately perceive the voice emitted from a speaker placed at the end of the cave. Reversely, if the listener is in the same area of sound source, or in the room where, according to legend, the Sibyl received travelers, the perception of the word is sufficient. The legend says that the predictions were expressed by Sibyl while the visitor walked down the hallway and in this condition the result is, according to the evaluations made, that speech understanding was weak, therefore, the voice of the Sibyl could not be clearly understood by the travelers, given them the feeling that the voice came from the depths of the cave.

7. CONCLUSIONS

The purpose of this work was to verify through the evaluation of acoustic properties if, as narrated by Virgil in the sixth book of Aeneid, the cave placed at the north west of the Gulf of Naples in the ancient town of Cuma in Campania (Italy), could be the home of an oracle. The Oracles were living in the cities provided with ports and they were often consulted by travelers to know their future.

By measuring the acoustic properties and using a software for acoustic simulation, it has been possible to evaluate the acoustic characteristics of the site by assessing the degree of speech intelligibility in the cave. Assumed, as handed down by the legend, that the Sibyl received travelers in the small room at the end of the long straight tunnel, the measurements were performed by placing the spherical omnidirectional source in the small room and the microphone stations, at a constant pitch, along the straight corridor.

The acoustic parameters representative of the speech understanding (STI, D50, and T30) show that when the listener is inside the small room, there is a sufficient speech intelligibility, while along the corridor the capability to understand speeches is poor along the corridor. The acoustic characteristics are, therefore, compatible with the believed condition of good speech intelligibility in the cave, while the visitor that walked down the corridor to reach the Sibyl was driven by a voice firstly incomprehensible and that

gradually became clearer. The sound perception received by the visitor, combined with the play of light and shadows that made unsettling the blurred priestly figure, have fueled the notoriety of this place so that the Cumaean Sibyl is considered one of the most intriguing and mysterious of classical ancient times.

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