AIR DOME ACOUSTICS

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Résumé

Le dôme pneumatique est une structure gonflable composée d'une ou plusieurs couches de membrane continue et flexible ancrée dans le sol qui est gonflée et soutenue grâce à de l'air comprimé. Dans cet article, nous abordons les résultats de mesurages acoustiques effectués à l'intérieur d'un dôme pneumatique. Dans ce type de structure, les valeurs de temps de réverbération aux fréquences moyennes, sont de plus de 8 secondes, ce qui a pour conséquence de réduire l'intelligibilité des instructions données par les entraineurs lors des phases d'entraiment. Avec l'aide d'un logiciel d'acoustique architecturale, l'ajout de matériau absorbant dans la coupole du dôme a été évalué comme possible correction acoustique pour réduire le temps de réverbération.

Mots clefs : acoustique des salles, simulation, modèle virtuel, dôme pneumatique

Abstract

Air dome is an air supported structure, it is a building composed by one or more layers of continuous flexible membrane anchored to the ground, inflated and supported by pressurized air. In the present work are shown the results of acoustic measurements inside an air dome. In this type of structure, reverberation time values, at the medium frequencies, are over 8 s and therefore with an excessive reverberation the ability to speech understanding is significantly reduced, so that during the training phases it does not correctly allow to understand the instructions of coaches. With the help of a software for architectural acoustics, a possible acoustic correction to reduce reverberation time was evaluated by introducing some sound absorbing material into the turned area of the air dome.

Keywords: room acoustics, simulation, virtual model, air dome

1 Introduction

The air domes are pressure static coverings born from the need of golf seasonal game management; they are generally used as coverings for tennis or basketball courts. The concept of air dome was proposed by the architect David H. Geiger at the Expo '70 in Osaka (Japan). The architect Davis Brody was encharged to realize the pavilion; he projected a 30 floor high building, but, due to the frequent earthquakes and typhoons in Japan, he asked for a help to the engineer Geiger. When the congress approved only half of the allocated budget, Geiger decreased the suggested height using an inflatable roof.

Air blowers pump air into the structure, creating a necessary air pressure that allows the fabric envelope to stay inflated. Air structures offer great flexibility and can be used as seasonal, permanent or temporary structures. Despite this flexibility, however, air structures are built to code and are structurally solid– even in inclement weather. An Air dome can be simply assembled and removed by acting on PVC cloth, inflation pressure that keeps the structure raised. PVC cloth is traction and tear resistant.

In order to prevent deterioration from moisture and ultraviolet radiation, these materials are coated with polymers such as PVC and Teflon. The pressure switch cover is essentially composed by a double PVC cover membrane, with a central tunnel with a semi-cylindrical shape stabilized by the introduction of compressed air, closed at both ends by two sails. In this last case, part of the air that is fed into the structure from the blower, is conveyed with a PVC hose between the two membranes, keeping in turn them into pressure and then detached from each other creating an air gap that allows to contain thermal losses. The air domes can take different shapes: ovals, half cylinders and hemispheres.

The air domes have the advantage to be cheaper than the traditional structures, and their installation is quicker, being flexible and very light structures.

Air domes reverberation time values are usually about 7.0 s at the middle frequencies. A reverberation like that is not a bad thing when it is related to sport activities because it can help to make sporting event more exciting and pleasing to the fans, while an excessive reverberation, present in that places, influences negatively acoustic performances, when air domes halls are used for sport training especially during the winter seasons. Therefore in these structures reverberation is excessive and the speech understanding is greatly reduced and during training phases it does not allow to understand coaches instructions correctly.

In some cases large sport halls have been adapted into places for music or for conversation events and the literature

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relates measurements and acoustic corrections of this places. [1, 2]. In California [3] the building of "San Diego Sports Arena" with an initial reverberation time of 5.0 s, was reduced to 2.6 s to perform music shows. For the "Arena of the Compaq Center", before it became the "Sanctuary of the Lakewood Church" [4], a mid-frequency acoustic correction was made. In Europe [5] some authors have proposed to cover the ceiling with absorbent materials as a solution for acoustic correction of sport halls or council rooms [6]. In the present work, using a software for architectural acoustics, it was evaluated a possible acoustic correction for reducing reverberation time, by introducing some sound absorbing materials into the turned area of the air dome.

2 Case study

The air dome considered is composed by a vaulted structure made of double-layer PVC sheets. The base has a simple rectangular shape of 35 m x 26 m, a maximum height of 11 m and the volume of 7,000 m^3, which is suitable for various sports such as basketball or volleyball. The pressure switch cover is essentially composed by a double PVC cover membrane, with a semi-cylindrical central tunnel stabilized by the introduction of compressed air, closed at both ends by two sails. In this last case, part of the air that is fed into the structure from the blower, is conveyed with a PVC hose between the two membranes, keeping in turn them into pressure and then detached one from each other creating an air gap that allows to contain thermal losses. Figure 1 shows the air dome internal view; Figure 2 shows the axonometric view of air dome; while Figure 3 shows the sections.

Figure 1: Air dome internal view

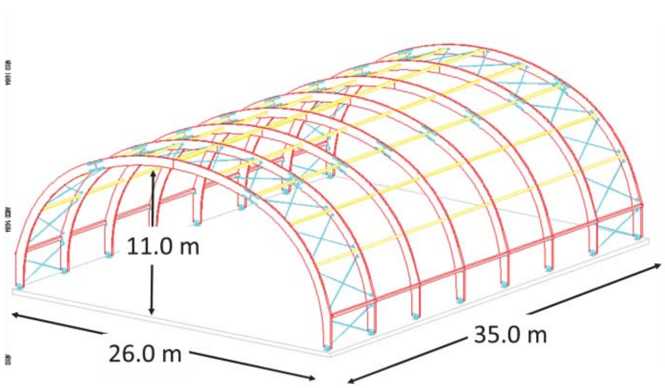

Figure 2: Axonometric view of the air dome

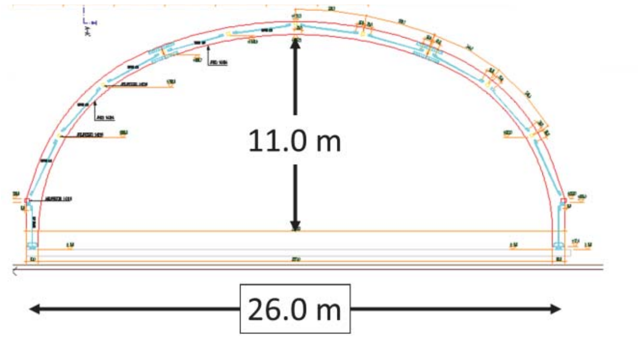

Figure 3: Section of the air dome

3 Acoustic measurements

In order to analyse the acoustic characteristics of the air dome, acoustic measurements were carried out using an impulsive sound source located in the central part of the playground. Acoustic measurements were done using small firecrackers as impulsive sound source. The height of sound source was 1.3 m from floor using a tripod. A microphone BRAHMA was used for recording impulse responses in nine different receivers located in fixed positions.

The choice of the impulsive sound source generated by the explosion of small firecrackers is due to the lack of electrical power and, as the room is huge, you have an adequate relation between signal and noise. The acoustic measurements were done in empty conditions, without spectators. The recorded impulse responses were elaborated with software Dirac 4.0, analysing the acoustic parameters defined in the ISO 3382-1 [7], such as reverberation time (T_{30}), EDT, clarity (C_{80} and C_{50}), definition (D_{50}), center time (Ts) and sound transmission index for speech intelligibility (STI).

In room acoustic evaluations, clarity represents the degree to which different reflections arrive and are perceived by the listener and it is assessed as an early-to-late arriving sound energy ratio. This ratio can be calculated for either a 50 ms or an 80 ms early time limit, depending on whether it respectively relates to conditions for speech or music [8].

In fact Table 1 reports the optimal values of the acoustic parameters in different musical listening conditions or speech intelligibility.

Table 1: Optimal acoustic parameter values for the different listening conditions.

Parameters	EDT, s	T_{30}, s	C_{80}, dB	D_{50}
Values for musical performances	1.8 < EDT < 2.6	$1.6 < T_{30} < 2.2$	$-2 < C_{80} < 2$	< 0.5
Values for speech performances	1.0	$0.8 < T_{30} < 1.2$		> 0.5

The acoustic procedure and post processing methodology were similar to those used in other spaces, such as large theatre and Odeon of Pompeii [9], theatre of

Benevento [10]. as well as in many other theatres. Figure 4 shows positions of the sound source of nine receivers (microphones) in the playground. Figures 5 to 10 show the average measured values of different acoustic parameters, in the octave bands from 125 Hz to 4.0 kHz. The values of EDT, T_{30}, C_{50}, C_{80} , D_{50} and Ts are reported at the interval of standard deviations, while STI = 0.18.

To understand the flutter echo phenomena, the parameter Centre Time (Ts) was considered. The center time (Ts) values of 90-160 ms are usually calculated for typical concert halls, principally at low-mid frequency.

In the air dome the measured values of EDT and T_{30} exceed on average 7.0 s at middle frequencies, while the average values of D_{50} = 0.15 and the average values of C_{80} = -8.0 dB.

The average value of the STI = 0.31. Low values of clarity (C_{80}) and definition (D_{50}) indexes and a large deviation of these parameters, sensible to the early part of impulse response, denoted that this acoustic parameters change from point to point.

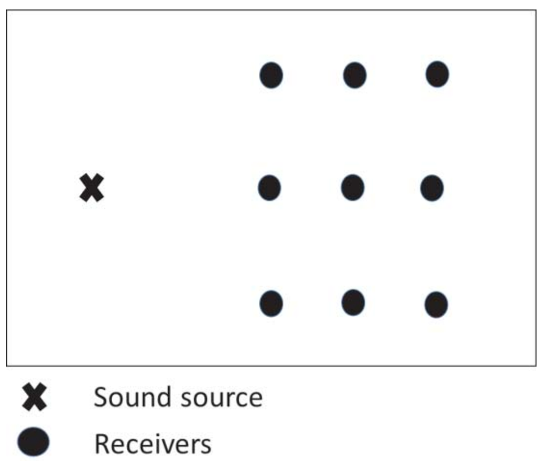

Figure 4: Plant with the indication of the sound source (X) and receivers (microphones) (o).

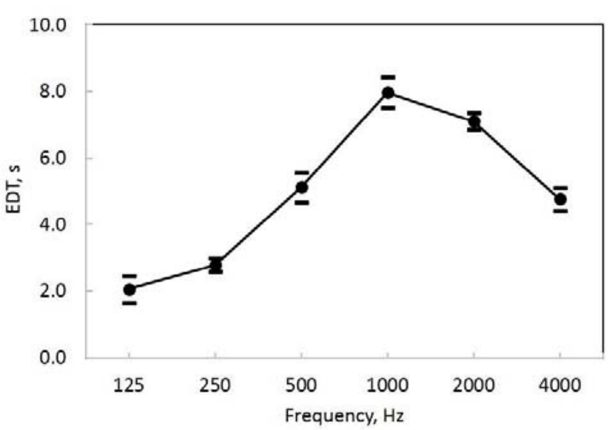

Figure 5: Measured average values of EDT ± 1 standard deviation.

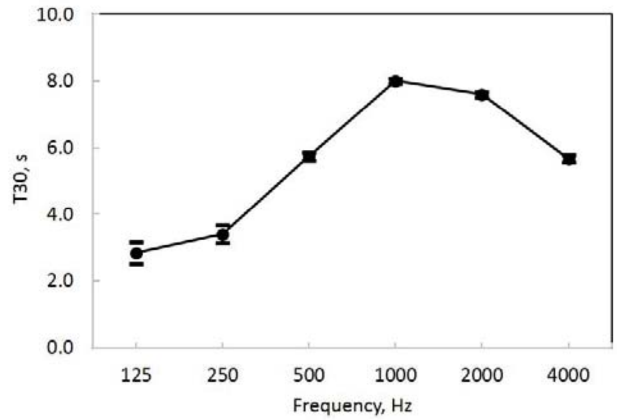

Figure 6: Measured average values of T30 ± 1 standard deviation.

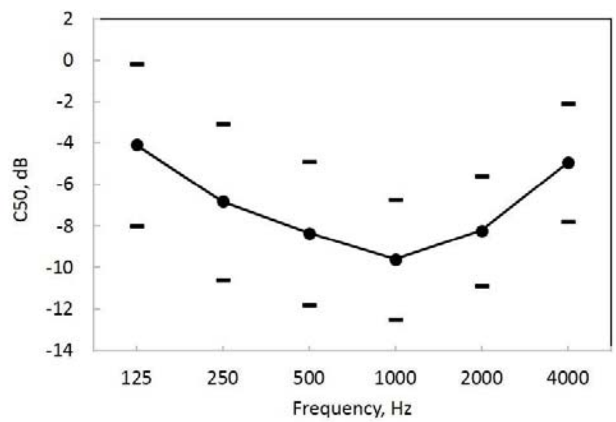

Figure 7: Measured average values of C_{50} ± 1 standard deviation.

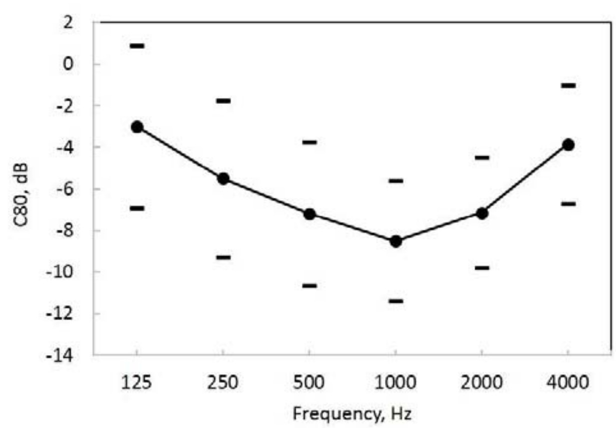

Figure 8: Measured average values of C_{80} ± 1 standard deviation.

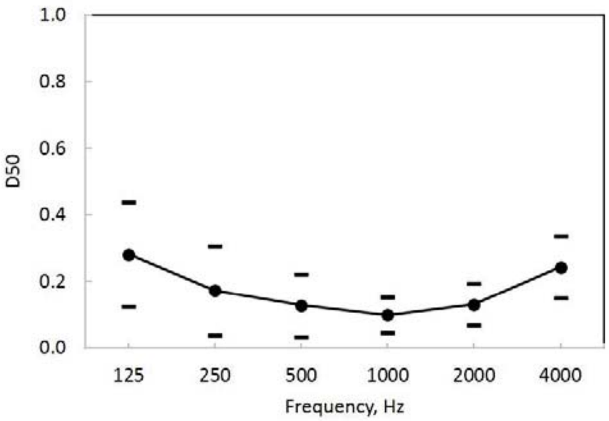

Figure 9: Measured average values of D50 ± 1 standard deviation.

For EDT and T_{30} only at a frequency of 125 Hz there is a sensible variation of the standard deviation. The measurement results suggest that a room in the observed state might not be well suited neither for musical concerts nor for speech intelligibility.

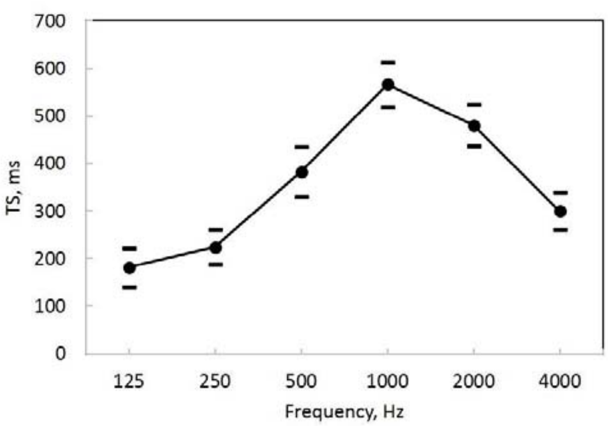

Figure 10: Measured average values of Ts ± 1 standard deviation.

The air dome does not perform criteria of good listening for speech. Furthermore to better understand acoustic conditions of the room they made measurements of the sound pressure levels during a basketball match; the measurements were performed with a Class 1 sound level meter, model SOLO 01dB, the LeqA = 72.5.0 dBA.

4 Air dome virtual model

To evaluate a possible solution to reduce reverberation time and allow the achievement of an adequate acoustic comfort to listen to music shows, the software for architectural acoustics "Odeon" was used with a virtual model realized by a 3D cad [11, 12].

Odeon is a software that uses the theory of rays with the method of images for the acoustic simulation. Using the software Odeon the calibration of the numeric model is required. Chosen the T30 as a reference parameter, the calibration consists in the change of the absorbent coefficient values of the walls so that the reverberation time measured doesn't coincide with the theoretic one. In the specific case the calibration was stopped when the difference between the time measured and the time calculated is inferior to 5% of all the octave bands calculated included between 125 and 4000 Hz.

Figure 11 shows 3D virtual model with the omnidirectional sound source and the receivers positioned in the measurement points put in the playground.

Table 2 shows the absorbent coefficient values of the air dome absorbent coefficient values used for the virtual model calibration.

Table 2: Octave band air dome sound absorption values

Frequency,	125	250	500	1 k	2 k	4 k
Air dome	0.28	0.22	0.14	0.08	006	0.02
Ground	0.01	0.01	0.01	0.01	0.01	0.01

The absorbent coefficient values decrease with the increase of the frequency, because at low frequencies the reverberation time is lower. Furthermore Figure 12 shows the 3D air dome virtual model with the indication of the sound reflection under the vault.

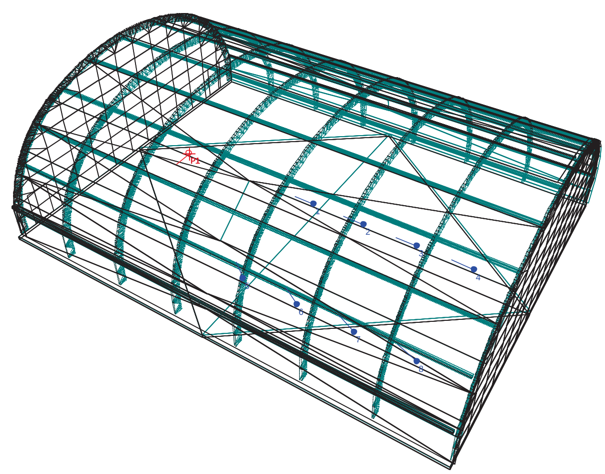

Figure 11: 3D air dome virtual model with omnidirectional sound source and receivers

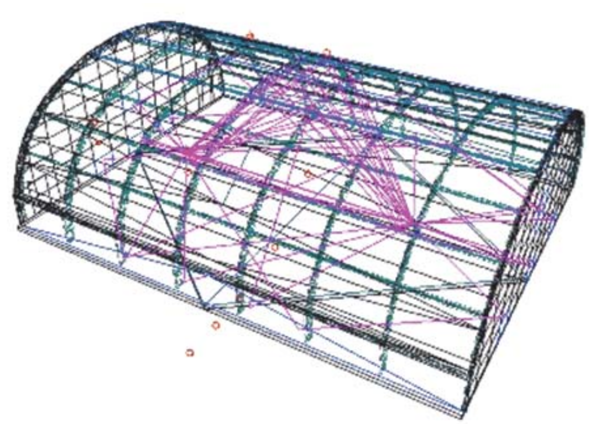

Figure 12: 3D air dome virtual model with the indication of the sound reflection under the vault

5 Materials for acoustic correction

To obtain the sound absorption coefficients to be used for a computer simulation of the dome acoustic correction, an impedance tube (tube of Kundt) was used according to ISO 10534-2 [13]. With this method is possible to obtain the absorbent coefficient measurements at normal incidence using samples of diameter 10 cm inside the tube. The impedance tube had an internal diameter of 10 cm (which correspond to an upper frequency limit of 2000 Hz). Various hypothesis have been evaluated for the acoustic correction of the air dome. Polyester absorbent panels, with thickness of 3.0 cm were chosen. The configuration considered corresponds to the suspended panels, so the panels are inserted as baffles.

Table 3 reports the octave band values of measured sound absorption coefficient for sample backed with anechoic termination. This average value of the absorbent coefficient is obtained from measurements with four different specimens (thickness 3.0 cm), the value of absorbent coefficient at 4.0 kHz is obtained by extrapolation of measured data. Figure 13 shows the particular of the material used for the acoustic correction; the material has closed cells, so it does not absorb moisture so that it can resist for long without an expensive maintenance.

Table 3: Octave band sound absorption coefficients measured according to ISO 10534-2 method

Frequency,	125	250	500	1 k	2 k	4 k
Alfa (α)	0.4	0.4	0.4	0.8	0.8	0.8

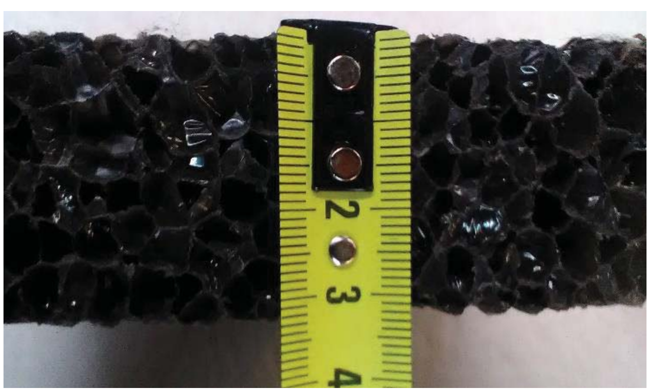

Figure 13: Particular of the material used for the acoustic correction

6 Acoustic correction

For the considered hypothesis it has been estimated an installation of a suspended panels made of soundproof material placed under webbed beams. The suspended panels are composed of 530 m^2 of absorbent material.

Figure 14 shows a 3D air dome virtual model with the absorbent panels under the vault. In this configuration the reverberation time estimated at 1.0 kHz is about 3.5 s. The presence of audience on the seats is negligible because the area covered by audience is little extended.

Figure 15 shows the comparison between reverberation time measured versus calculated time with the acoustic correction.

Figure 16 shows the comparison between D_{50} versus calculated with acoustic correction Figure 17 shows the comparison between C_{80} versus calculated with acoustic correction.

Figure 18-A shows the impulse response of the central point, obtained with the Odeon software, closer to the source in the configuration without acoustic correction. Whereas, Figure 18-B shows the impulse response obtained with the Odeon software for the same point, when sound absorbing material for acoustic correction is applied under the dome.

Figure 19-A shows the impulse response of the central point, obtained with the Odeon software, farther to the source in the configuration without acoustic correction. Whereas, Figure 19-B shows the impulse response obtained with the Odeon software for the same point, when sound absorbing material for acoustic correction is applied under the dome. In the absence of acoustic correction, the effect of reflection on the dome can be noted, while in the presence of acoustic correction this effect is far more limited.

Figure 14: 3D air dome virtual model with the absorbent panels under the vault

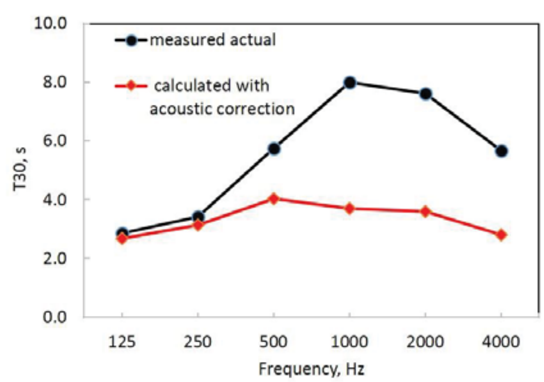

Figure 15: Comparison between reverberation time measured versus calculated time with acoustic correction.

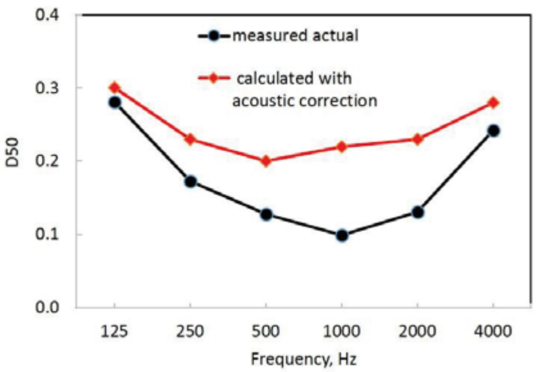

Figure 16: Comparison between D_{50} measured versus calculated with acoustic correction

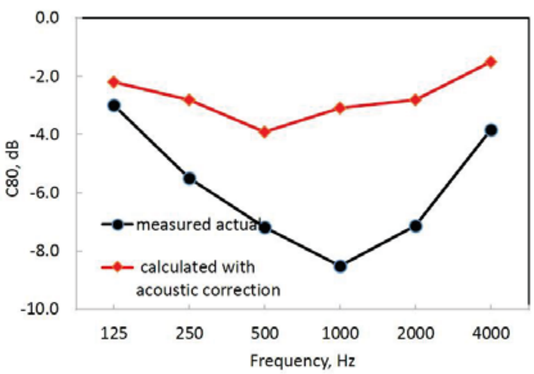

Figure 17: Comparison between C_{80} measured versus calculated with acoustic correction

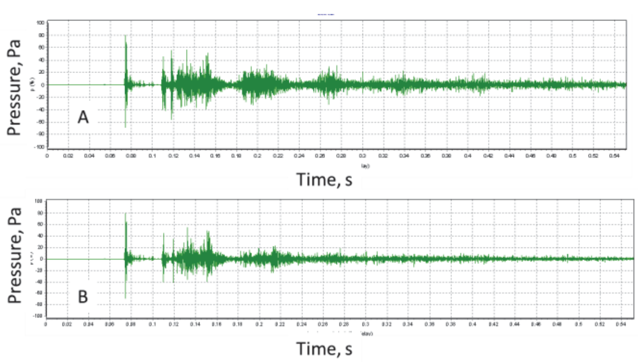

Figure 18: (A) Impulse response of the central point obtained with the Odeon software, without acoustic correction. (B) Impulse response when sound absorbing material for acoustic correction is applied under the dome.

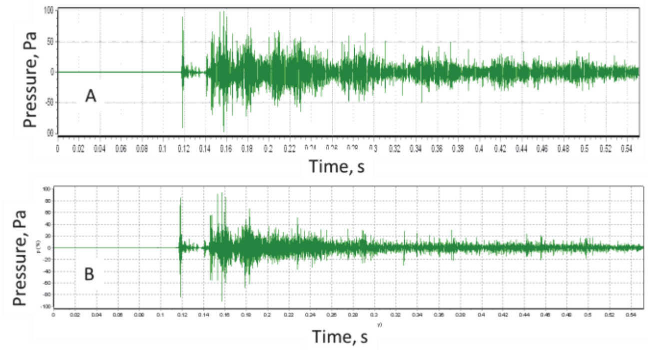

Figure 19: (A) Impulse response of the central point obtained with the Odeon software, without acoustic correction. (B) Impulse response when sound absorbing material for acoustic correction is applied under the dome.

7 Discussion

Several authors have provided the optimal values of the acoustic parameters in order to listen to music or speech since the reverberation time is not enough to assess the acoustic goodness of a room. For a good understanding of speech, it is worth evaluating the definition D_{50} (in a room with good speech understanding conditions, $D_{50} > 0.50$). For good music listening, it is worth evaluating the parameter C_{80} (in a hall, the values of C_{80} should be in the range between -2 dB and 2 dB for good music listening).

For the air dome the D_{50} values decrease with the frequency, because the reverberation time values increase. The value of T_{30} at the frequency of 1.0 kHz is about 8.0 s, so in this configuration the speech understanding is very low. After the acoustic correction the reverberation time at the frequency of 1.0 kHz is 2.5 s. The value of STI = 0.42.

8 Conclusions

This paper shows the possibility to obtain a good acoustic correction inside an air dome, using absorbent material under the vault. The sound absorbing material chosen for the acoustic correction shows good absorbing values and is a moisture proof material, as moisture is very frequent in these spaces. The study of the acoustics of the air dome carried out with acoustic measurements and the architectural acoustics software "Odeon" gives useful information to improve the acoustic of the room. The proposed hypothesis of acoustic correction has been designed in order to reduce reverberation time, consequently improving the listening condition during the training activities.

References

[1] K.A. Penman , J.S. Englund, and N. Stanier. Reverberation and noise levels in sports areas, *Journal of the Acoustical Society of America,* 62, 1046-1048, 1977.

[3] M. Klasco, and R. Paolini. San Diego Sports Arena.*dB*, November / December, 29 -34, 1987.

[4] B. Russ. From Sports Arena to Sanctuary: Taming a Texas-sized reverberation time. *Acoustics Today*, 7, 24-28, 2011.

[5] R. Bošnjakovic and D. Tomic. Acoustical Treatment of Multipurpose Sport Halls. *Proceedings of 3rd Congress of the Alps Adria Acoustics Association*, 27–28 September, Graz – Austria. 2007.

[6] G. Iannace. Sport Hall Acoustics. *Noise & Vibration Worldwide*, 46, 22-29, 2015. doi:10.1260/0957-4565.46.10.22

[7] ISO-3382, Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters

[8] M. Barron, *Auditorium Acoustics and Architectural Design*, E&FN SPON, London, 1993

[9] U. Berardi, G. Iannace and L. Maffei. Virtual reconstruction of the historical acoustics of the Odeon of Pompeii, *Journal of Cultural Heritage*, 19, 555-566, 2015. doi: 10.1016/j.culher.2015.12.004

[10] G. Iannace and A. Trematerra. The rediscovery of Benevento Roman Theatre Acoustics. *Journal of Cultural Heritage* 15(6). 698-703, 2014. doi: 10.1016/j.culher.2013.11.012

[11] www.odeon.dk, user manual - version 11

[12] X. Zeng, C. L. Christensen and J. H. Rindel. Practical methods to define scattering coefficients in a room acoustics computer model. *Applied Acoustics*, 67, 771 – 786, 2006.

[13] EN ISO 10534-2. Acoustics - Determination of sound absorption coefficient and impedance in impedances tubes Transfer-function method