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AcousticalMeasurements for a small College Auditorium using Sinusoidal Tones

Cruz-Miranda, Erik[1]; Guerrero-García Ignacio Alonso[2]; López-Flores Yvan[3]; Franco-Galván Carlos Angel[4]
Facultad de Artes BUAP
1 percuerik@gmail.com, 2 jetromanfariel@gmail.com,3 yvancinevideo@gmail.com, 4 carlosangel.franco@correo.buap.mx
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Abstract
Acoustical measurements in a college auditorium took place using an empirical version of Sweep Sinusoidal. A first set of measurements were taken without anti-reverberant treatment of the walls. A second stage of the test was carried out with minor acoustical modifications on the building. A noticeable improvement was observed during this stage, particularly in amplitude loss in frequencies around 80 Hz.
Keywords: Sweep Sinusoidal, acoustic measurements, room acoustics.

I. INTRODUCTION

Buildings dedicated to musical presentations or conferences need a good acoustical environment according depending on the events that occur inside. More than often, changes on its walls, floors and ceilings are needed. Position of the seats andcovering of windows. A group of researchers in the Department of Arts(*Facultad de Artes)* at the Autonomous University of Puebla BUAP, Mexico decided to study the acoustical response of a small auditorium located at the city center campus of the university.

A two-stage experiment was carried out where amplitude of sinusoidal waves was measured at different frequencies (80, 150, 300, 1000 and 8000 Hz). The first stage took place without any modifications on the building. Subsequently, a second set of amplitude measures at the same frequencies were done having the building modified with minor acoustical refurbishments. The document is organized as follows: After this introduction, section 2 describes the methodology applied. Section 3 states the experiment's aims. Section 4 contains a historical review on the building. The experiment is described in sections 5 and 6. Section 7 shows the results and conclusions are explained on section 8.

II. BACKGROUND

Measuring the acoustical response of a building has become a standard in building industry, recently (Tenutta et al., 2019)used this technique to refurbish audiometer cabins. The same technique was applied in the construction of a university auditorium(SALVADOR GIL SANCHIS, 2020). A similar method was used during the remodeling of public auditoriums in Valencia, Spain (Javier & Guzmán, 2020).

Among the different techniques to measure acoustical responses, the Sweep Sinusoidal is one of the most notorious ones(Bjor & Nikolic, 2004). It is based on directly obtaining the venue´s impulse response which is necessary to know the reverberation time at different frequencies.

For this experiment, the authors used an empirical method based on Sweep Sinusoidal technique. The main difference is that four discrete points in frequency instead of using a continuous sinusoidal sweep. The impulse response was not calculated since the main interest was the amplitude values at five frequencies: 80, 150, 300, 1000 and 8000 Hz.

III. EXPERIMENT AIMS

The main goal in this experimentwas to diminish the attenuation of certain frequencies which are relevant to the human ear. A secondary objective is to document the auditorium´s attenuation values to keep them as a reference for future work.

IV. HISTORICAL INFORMATION ON THE BUILDING

The auditorium where the experiments were caried out is part of a building form 1824 whose first owner was Esteban Munuera, commander and governor of the State of Puebla (Bühler, 2001).It was acquired by the University in 1987 and a center for Language learning was established on it. From 2018 to present day belongs to the Department of Arts (Music). It is located on 4 oriente 414in historical city center.

A small space was designated as an auditorium for concerts, conferences, and artistic events. Some modifications are needed to make it suitable for musical purposes, hence the need to learn about its acoustical features.

The physical space where the auditorium is, despite its age, it is perfectly well preserved, and it still built with the materials used in the 18th century. The walls have several layers of rock, river stones, brick, and mortar,see Figure 1.It consists of a rectangular space with two large windows of 3 mheight, 2 m wide.The roofis composed of a set of beams that support bricks. Over them a layer of morter is applied and above all a new layer of bricks, which at the same time covers the floor.

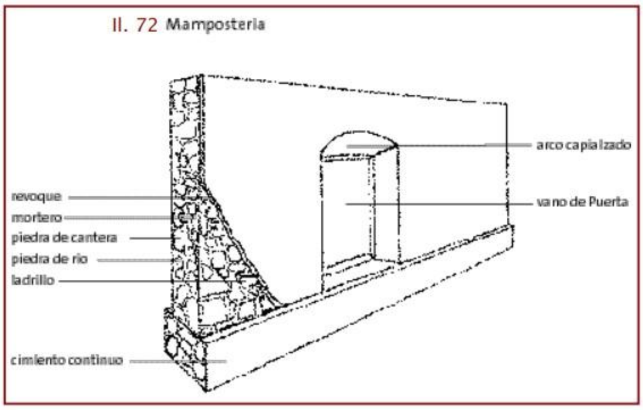

Figure1. Wall material

V. EXPERIMENT METHODOLOGY

Two stages were planned for the experiment, the first stage consisted of measuring the room response without acoustical modifications and the second stage had some minor modifications on the room, The following instrumentals were employed:

Table1 Instrumental

Element	Model
Decibel Meter	D525
Loudspeaker	Soundlink
Wave Generator (Software)	N/A
Fabric (curtain)	11% cotton y 89% polyester

The procedure was as follows:

Montage: The loudspeaker was placed at the center of the stage, where usually the musicians stand. The room was closed, and the people who measured stood at different distances form the sound source.For the second stage,curtain was placed over the window.

Measuring and Data capture: On the wave generator, sinusoidal waves were producedat 80Hz, 150Hz, 350hz, 1000Hz y 8000Hz. The people who measured stood at 2m, 4m, 6m, 8m and 10m, where the auditorium chars are placed.The procedure was the same on both stages except for the curtain on the window to absorb the traveling sound waves in the second stage.

VI. Experimental Work

This part of the document describes how the measures were realized on the building. As it was discussed previously, the experiment had two stages: One without building modifications and the second one having minor modifications in the building.

Sound Level measures: Stage One

As it was mentioned before, five frequencies were chosen to measure the sound level: 80Hz, 150Hz, 350 Hz, 1000Hz y 8000Hz.It is worth mentioning that during the measuring, no student activities existed due to Covid -19 lockdown. Figure 3 shows the building locating in the city, figure 2 has some photographs of the auditorium.

Figure 2"Inside the Auditorium"

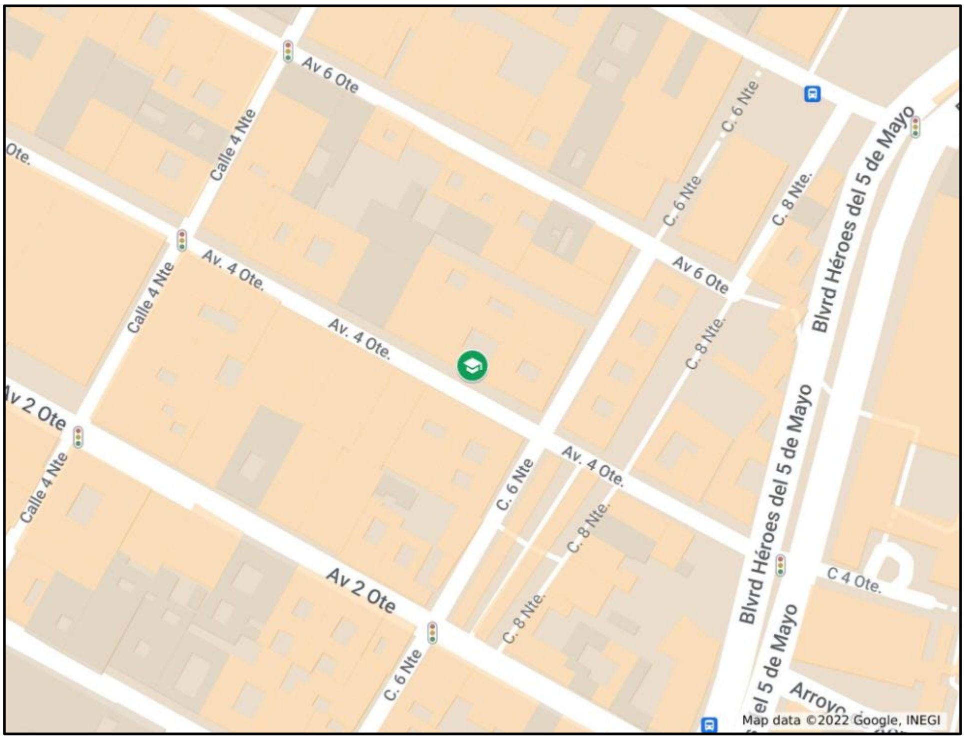

Figure3"Building Location". Source: GoogleMaps

Figure 4 shows an auditorium plane with its dimensions, and figure 5 contains a description where the sound meter was placed during the measuring. Those placings were determined according to the seat location.

Figure4"Auditorium Plane"

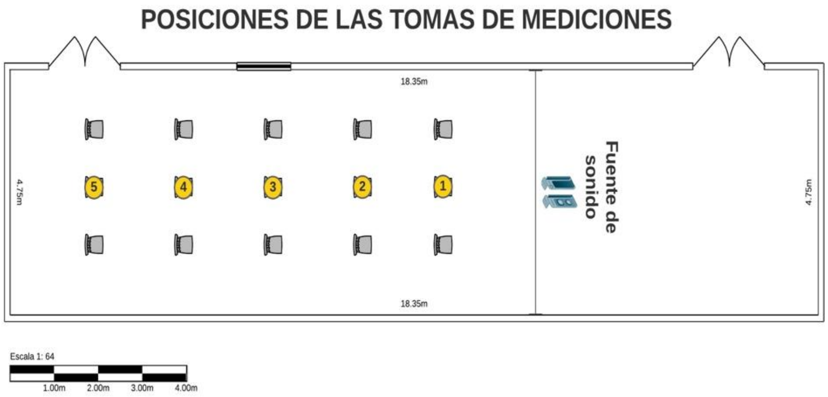

Figure5“Placement of the soundmeter”

Sound Level measures: Stage Two

According to the original proposal, to reduce the waves dispersion and improve the listening experience, it was planned to place anti-reverberant elements, particularly on the windows. Curtains were placed on the windows; anti- resonant panels were considered but not used in the end due to certain legal restrictions on historical buildings modifications.

The same placements of the sound meter were reproduced in this second stage as it was shown in figures 4 and 5.

VII. Results

The resulting levels are shown on the following tables. Table 1 contains the values obtained on the first stage. Average, variance, and standard deviation are included to statistically validate our results.

Table 2 shows the values read on the experiment’s second stage. Figures 6 and 7 show the same results graphically to give the reader a visual aid.

Table1 “Values obtained on Stage One”

Stage One Amplitude Readings								
Distance form source (m)	**Amplitude at80 Hz (dB)**	**Amplitude at150 Hz (dB)**	**Amplitude at350 Hz (dB)**	**Amplitude at1k Hz (dB)**	**Amplitude at8kHz (dB)**	**Average**	**Variance**	**Std. Deviation**
2 m	70	80	79	79	73	76.2	15.76	3.9
4 m	63	80	74	80	71	73.6	40.24	6.3
6 m	65	80	77	77	73	74.4	27.04	5.2
8 m	73	75	80	74	66	73.6	20.24	4.5
10 m	73	78	79	75	64	73.8	28.56	5.3

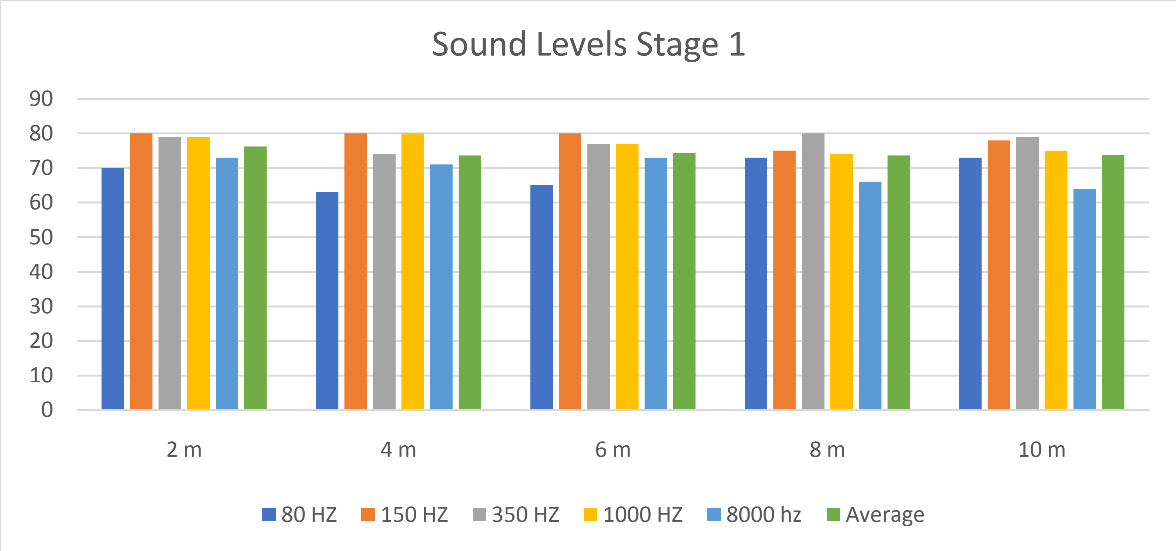

Figure6 "Resulting Amplitude Values on Stage One"

Table2"Values Obtained in Stage Two"

Stage Two Amplitude Readings								
Distance from Source (m)	**Amplitude at 80 Hz (dB)**	**Amplitude at 150 Hz (dB)**	**Amplitude at 350 Hz (dB)**	**Amplitude at 1kHz (dB)**	**Amplitude at 8 kHz (dB)**	**Average**	**Variance**	**Std. Deviation**
2 m	64	92	97	102	78	86.6	191.84	13.9
4 m	52	84	114	84	73	81.4	402.24	20.1
6 m	53	90	106	84	73	81.2	312.56	17.7
8 m	53	93	101	90	71	81.6	301.44	17.4
10 m	50	80	94	92	71	77.4	257.44	16.1

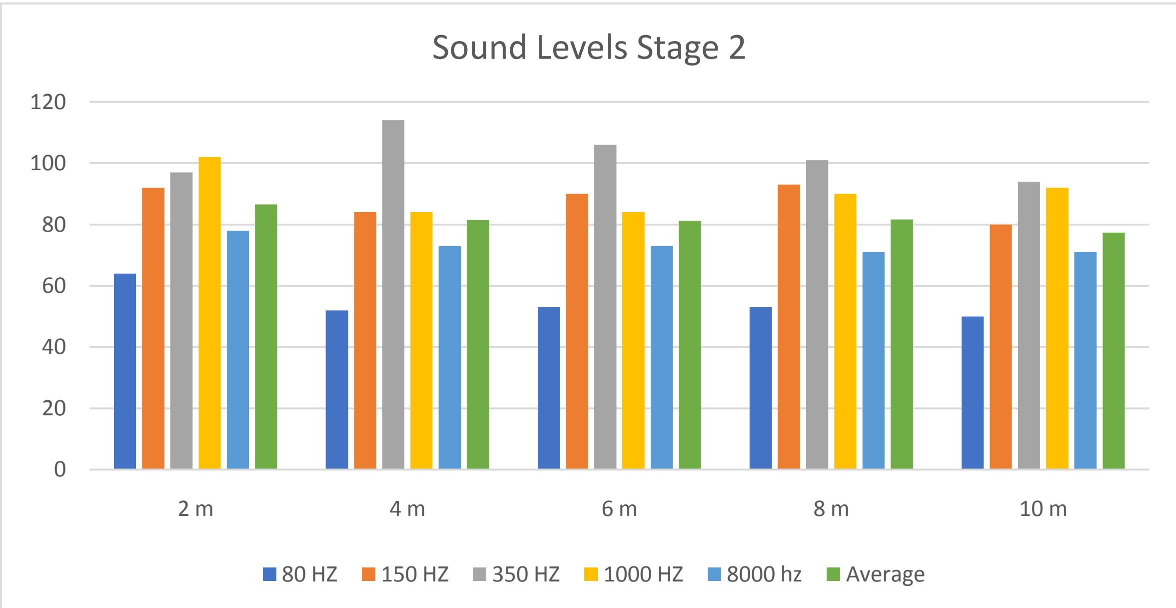

Figure7""Resulting Amplitude Values on Stage Two"

It can be seen on both graphs that the average amplitude level was 75 dB on all frequencies. After the second stage, the average increased up to 80 dB, placing anti resonant materials produced a 5 dB gain, particularly on lower frequencies. We can see the advantage of modifying the room using anti resonant materials.
An interesting case is that of 150 Hz, which is a common frequency to be perceived by the human ear, it is present in most musical instruments including the human voice.

Table3"Comparing Amplitude readings at 150 Hz"

150 Hz		
Distance(m)	Amplitudes (dB) StageOne	Amplitudes (dB) StageTwo
2	80	92
4	80	84
6	80	90
8	75	93
10	78	80

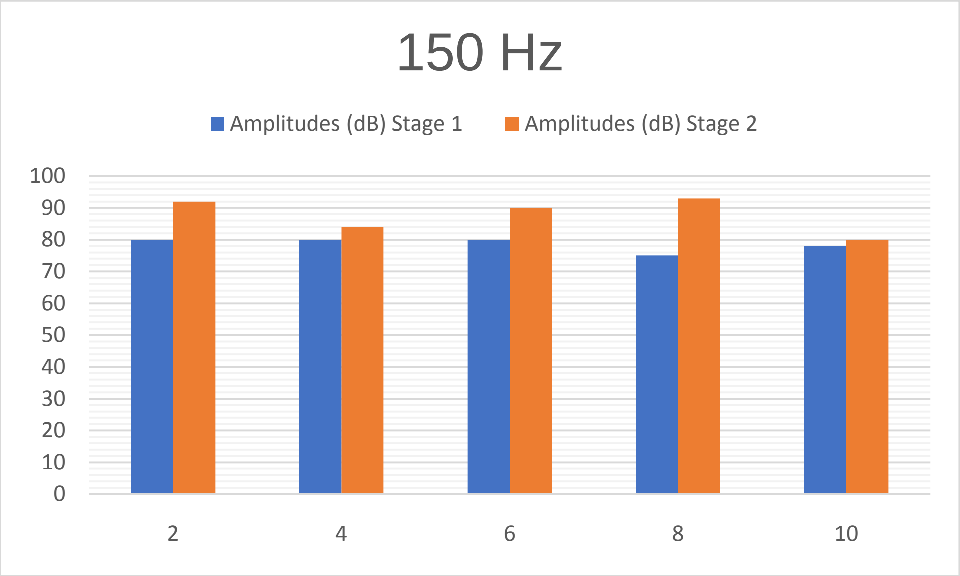

Figure8 “Data on amplitudes at 150Hz”

After studying the results on stage two, with the acoustically modified auditorium, there are amplitudes up to 12 dB larger than those measured in stage one.

VIII. Conclusion

It is well known that data can vary with a different sound source other than sinusoidal. Nevertheless, the results were good enough to assume that a similar condition will occur with multiple harmonics waves.

Just as it is discussed in specialized texts on acoustics (Everest & Pohlman, 2009), it was proved that frequencies under 100 Hz tend to be the most attenuated in auditoriums. Frequencies above 200 Hz to 1.5 kHz are usually well perceived anywhere in the building.

No major changes are needed, placing curtains improves the acoustical response considerably. Moving acoustic panels or curtains are suggested on the other side of the building on the walls.

A couple of issues came up once finished this experiment. The first one has to do with the room’s impulse response. If calculated, it must be consistent with the obtained measures. The second issue is to realize a similar experiment with the auditorium full of people with a musical event, the measures must be like the ones read in this experiment.

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