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Study of Acoustic Waves in a Teaching Classroom using Finite Element Method

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To understand the behavior of acoustic waves in a specific classroom in order to get a configuration of panels and ceilings configuration to improve reception and clarity of internal sounds. This was possible by the modification of the properties of the enclosure, sush as the absorption coefficients of internal surfaces. The analysis was carried out through the implementation of a model by using Finite Element Method.

Study Design: The acoustic behavior that enclosure for academic use require is discussed, indicating that it is common to find deficiencies in the acoustic architecture of enclosures, and the risks that this causes to cognitive and academic development, as a consequence of low understanding.

Place and Duration of Study: Graduate Engineering Department, Universidad Autónoma de Querétaro, between August 2020 and June 2021.

Methodology: The problem is solved by applying the finite element method. This implies that the essential concepts for the understanding of this subject are reviewed, such as; acoustic physics, mechanics of the continuous medium and finite element method.

Results: After multiple analized scenarios, it was observed that while there is an absorption greater

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than the surface, the material of the panel or ceiling is not relevant. On the other hand, the size and surface where is located the panels turned out to be more relevant parameters.

Conclusion: Considering the proposed alternatives, an increase in the Sound Pressure Level and a uniform distribution can be observed. The use of computational tools help to understand the behavior and distribution of acoustic waves in the classroom, which can provide an overview of different adaptations.

Keywords: Finite element; acoustic architecture; scholar enclosure; acoustic adequacy; analytic method.

1. INTRODUCTION

The acoustic condition in an educational enclosure is important for learning, listening clearly could be the key between understanding or not [1-3], this is influenced by the way in which acoustic waves are propagated in space [4,5]. Unfavorable conditions also affect teachers due to excessive vocal effort [6-8]. The classrooms construction doesn´t normally consider acoustic criteria, using materials with low absorption coefficients [7], resulting in conditions that don´t fulfill the requirements [9,10]. In these cases, it will be necessary to intervene the enclosure by an adequacy, in order to enhance the clarity of the message [5].

To avoid wave reflection; Pérez-Egea et al. [5] suggest considering surfaces with the ability to enter into vibration to dissipate energy, as well as the use of less rigid materials. Cravero et al. [9] solved this problem through implementation of sound absorbing panels. A computational model was necessary in order to know the acoustic behavior of the room with different panel locations. Also, the placement of materials with high roughness can be considered in these cases, they have a high absorption coefficient. Absorbent materials are porous, generally made up of fibrous or granular substances, such as; fiberglass, mineral fiber, resin-based foam and polyurethane foam [11,5].

Currently there are studies, techniques and tools to achieve acoustic adjustments, however, there isn´t properly a formal study in this area [6,12]. Postma and Katz narrate that they began their study [13] with experiments; this gave them data that didn´t match with previous information from their enclosure. A computer modeling was carried out, when it was calibrated with information from the new experiments; they found that there were certain factors that influenced the changes seen. Therefore, is emphasized the necessity to formalize studies and analysis in the area of acoustics [14].

Nowadays it is common to use various specialized software in designing and adequacy of enclosures [15], it is possible to apply modifications to rooms and evaluate the results without making physical modifications to the classroom, with it is a clear advantage over empirical methods [9].

The aim of this work is to modify properties of an academic classroom, such as the absorption coefficients of surfaces, in order to have favorable acoustic properties for understanding. The analysis was carried out through the implementation of an energetic study, using the ANSYS, Mechanical APDL software as a computational tool, and with the implementation of Continuous Medium Mechanics, Fluid Mechanics and Finite Element models. This is to obtain a correct parameterization and solution for these types of problems. In addition, recommendations were obtained for the improvement and adequacy of academics enclosures.

2. MATERIAL AND METHODS

2.1 Discrete Model Physical Phenomenology

In this section are described the equations that will govern the proposed model for acoustic analysis, based on extracts of pertinent information from books by Gurtin [16], Hartmann [17] and Beléndez [18], and having the User Manual of the software Mechanical APDL ANSYS 14.0 as a reference for application.

The model has two principal components; the structural one and the medium in which the waves are transmitted (fluid), therefore, there will be an acoustic fluid-structure interaction problem.

Fist, the Navier-Stokes equation (1) is considered to descrive the behavior of elements related to the fluid that will act as medium of transmission (air).

$$\rho v' + (\mathrm{grad}\, v)\rho v = \mu \Delta v - \mathrm{grad}\, \pi + b \quad (1)$$

ρ is the medium Density, v is the Velocity vector, μ is the fluid Viscosity, π is the Hydrostatic Pressure, b is the Body Force Vector.

In the same way, the equation of Dynamic Equilibrium (2) is involved in the description of deformable solids behavior of the model.

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F\} \quad (2)$$

M is the Mass Matrix, C is the Damping Matrix, K is the Stiffness Matrix, u is the Displacement Vector (and their derivatives with respect to time), F is the Force Vector.

The following fluid statements are considered: The Fluid is compressible (density changes due to pressure variations). The fluid is not viscous. (There is no viscous dissipation). There is no medium flow in the fluid. The mean density and pressure are uniform throughout the fluid.

With these considerations, it is obtained the Acoustic Wave equation (3).

$$\frac{1}{c^2}\frac{\partial^2 P}{\partial t^2} - \Delta P = 0 \quad (3)$$

P is the Acoustic Pressure, c is the Sound Velocity given by the equation (4).

$$c = \sqrt{k/\rho_o} \quad (4)$$

k is the compressibility modulus of the fluid. ρo is the mean Density of the fluid.

After discretizing the equation (3) and by applying de Form Functions, is obtained the Mass Matrix of fluid (5), the Stiffness Matrix of fluid (6) and the Coupled Mass Matrix (7). These matrices together form the Discretized Wave equation (8).

$$[M_e^P] = \frac{1}{c^2}\int_V \frac{1}{c^2}\{N\}\{N\}^T dV \quad (5)$$

$$[K_e^P] = \int_V [B]^T[B] dV \quad (6)$$

$$\rho_o[R_e] = \rho_o \int_S \{N\}\{n\}^T\{N'\}^T dS \quad (7)$$

$$[M_e^P]\{\ddot{P}_e\} + [K_e^P]\{P_e\} + \rho_o[R_e]^T\{\ddot{u}_e\} \quad (8)$$

The finite element approximation for Pressure is applied. The Dissipation term is added to equation (8). After an accommodation, are obtained the Fluid Damping Matrix (9) and the Discretized Wave equation (10) considering the loss energy at surface of absorbing boundary.

$$[C_e^P] = \rho_o Y \int_S \{N\}\{N\}^T dS \quad (9)$$

$$[M_e^P]\{\ddot{P}_e\} + [C_e^P]\{\dot{P}_e\} + [K_e^P]\{P_e\} + \rho_o[R_e]^T\{\ddot{u}_e\} = \{0\} \quad)$$

To describe the fluid-structure interaction problem, it is necessary to consider the Load Vector due to the Fluid Pressure on interface (S), defined in equation (11). Having as a result, the Dynamic equation (12).

$$\{F_e^{pr}\} = \int_S \{N'\}P\{n\} dS \quad (11)$$

$$[M_e]\{\ddot{u}_e\} + [C_e]\{\dot{u}_e\} + [K_e]\{u_e\} = \{F_e\} + \{F_e^{pr}\} \quad)$$

The Finite Element approximation of Pressure function is applied to equation (11), by simplifying is obtained the vector presented in equation (13). Considering this, the eqation (12) can be rewrite as shown in eq. (14).

$$\{F_e^{pr}\} = [R_e]\{P_e\} \quad (13)$$

$$[M_e]\{\ddot{u}_e\} + [C_e]\{\dot{u}_e\} + [K_e]\{u_e\} - [R_e]\{P_e\} = \{F_e\} \quad (14)$$

Equations (14) and (10) describe the complete behavior of the discretized finite element fluid-structure interaction problem, which assembled result in equation (15).

$$\begin{bmatrix} [M_e] & [0] \\ [M^{fs}] & [M_e^P] \end{bmatrix}\begin{Bmatrix} \{\ddot{u}_e\} \\ \{\ddot{P}_e\} \end{Bmatrix} + \begin{bmatrix} [C_e] & [0] \\ [0] & [C_e^P] \end{bmatrix}\begin{Bmatrix} \{\dot{u}_e\} \\ \{\dot{P}_e\} \end{Bmatrix} + \begin{bmatrix} [K_e] & [K^{fs}] \\ [0] & [K_e^P] \end{bmatrix}\begin{Bmatrix} \{u_e\} \\ \{P_e\} \end{Bmatrix} = \begin{Bmatrix} \{F_e\} \\ \{0\} \end{Bmatrix} \quad 15)$$

With:

$$[M^{fs}] = \rho_o[R_e]^T$$
$$[K^{fs}] = -[R_e] \quad (16)$$

It have been obtained the equation of fluid-structure interaction problems. Where the matrix with superscript p and the matrix [R_e] are generated by the acoustic fluid element, and the rest by the structural elements.

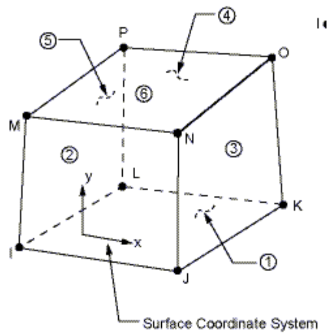


Fig. 1. Cubic form of Finite Element used in calculation of fluid behavior

The Finite Element used will be one of the family of hypercubes, commonly used in fluid modeling and interface of fluid-structure interaction problems. Each nodes of this element have four degrees of freedom; translation in three directions and pressure. The translation is only applicable to those nodes that are in the fluid-structure interface. The element considers the damping due to the sound absorption of enclosure's surfaces materials, as well as the damping of the fluid itself. Fig. 1 shows the geometry, location of nodes and the coordinate system of the element. The fluid information required by the element is the reference pressure, sound speed and fluid density.

2.2 Case Study

It is a U1C (Urban 1-level Concrete) classroom from the Mexican Administrative Committee of Federal School Construction Program (CAPFCE) [2]. Construction with one level, structure type A, base of rigid reinforced concrete frames, with longitudinal spans of 8.00 m and transverse spans of 3.24 m. (Fig. 2).

As the Fourier Theorem indicates; a complex wave can be built by adding a set of simple sine waves, this offers the possibility of analyzing the acoustic behavior of a room using simple wave signals [17]. 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were the frequencies used in the simulation for the acoustic analysis. The height of the source is proposed considering the height of the average Mexican of 1.61 meters [19]. In the other directions, the possible scenarios shown in Fig. 2 were considered. Therefore, it was taken a distance in direction x of 1.00 meter. While for Scenario A, B and C the distances in z were 1.75, 4.00 and 6.25 meters, respectively.

The absorption coefficients are not constant, they vary depending on the study frequency. Table 1 shows the absorption coefficients of the different materials of enclosure surfaces, these were obtained from the annex to the Recuero´s book Acoustics Architectural [20].

2.3 APDL Parametric Computational Model

By writing a code, was programmed a routine to perform the analysis of acoustic behavior of the studied room.

In the Information Macro, the properties of the classroom are entered.

Fig. 2. Enclosure studied, extracted from the Mexican Institute of Educational Physical Infrastructure (INIFED) [2] & Locations of Sound Source

Table 1. Absorption coefficients (α) for the different materials and frequencies used in the model [20]

Material	Frequencies (Hz)					
	125	250	500	1000	2000	4000
Painted Brick	0.012	0.014	0.017	0.020	0.023	0.025
Painted Concrete	0.010	0.010	0.010	0.020	0.020	0.020
Floor Tile	0.010	0.010	0.010	0.020	0.020	0.010
Glass of Windows	0.035	0.040	0.027	0.030	0.020	0.010
Normal Concrete	0.010	0.012	0.020	0.020	0.023	0.035
Fiberglass Panel	0.230	0.560	0.770	0.860	0.950	0.980
Wool Felt	0.090	0.340	0.550	0.660	0.520	0.390

In the Elements Macro, the properties of the materials are established, as well as the different types of finite elements. The mechanical properties of the materials involved in the analysis are defined, as well as the geometry of Structural Members. The thicknesses of the flat elements, such as windows, roof, walls, etc, are indicated too.

In the Geometry Macro; it is built the model by generating the required lines, using these, the areas corresponding to flat elements are created. Analogously, volumes are generated.

In the Mesh Macro; the geometric entities are meshed. The shape of the finite element (tetrahedral) is defined, as well as its size. The attributes of geometric entities are indicated. Once the model is meshed, the volumetric elements can be seen as in Fig. 3.

The next is to define the restrictions in the Restrictions Macro, as well as information of the harmonic excitation of acoustic analysis, such as amplitude, location and frequency. The fluid-structure interface location is indicated. Restrictions are considered in the base of model, at these points there will be null displacement and pressure.

In the Solution Macro, the matrices are generated and the system is solved. With this, the pressure field in the classroom domain is obtained and, consequently, the value of the Sound Pressure Level at any desired point.

3. RESULTS AND DISCUSSION

Fig. 4 shows the pressure field. The pressures in those elements that make up the boundary of the enclosure are shown. It is observed that the pressures range from -0.531E-04 T/m^2 (-0.521 Pa) to 0.463E-04 T/m^2 (0.454 Pa). This assumes maximum Level points of 88.3 dB and 87.1 dB respectively, this values are too high compared with maximum recommended [2] of 75 dB, but considering adequacy this values low considerably (Fig. 6 and Fig. 7). When talking about acoustic waves, we are dealing with impulse transmissions, this means that particles of fluid will get closer and away from each other, this causes a fluctuation in density which translates into a pressure change between positive and negative values, as obtained in the analyzes shown below.

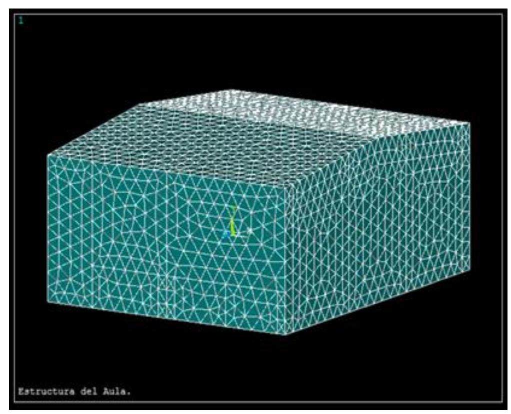


Fig. 3. Meshing obtained from the volumetric elements

The plane at height of 1.00 m was revised, shown in Fig. 5. At this height is where the receiving sources of the signals will be found, this is where the ears of the classroom users will be. The classroom is shown without any type of adequacy (Fig. 5 (a)), and the case in which panels of 1.10 meters per side are applied (Fig. 5 (b)). It is observed that, despite having higher pressures in the improved enclosure, these are distributed more uniformly and don´t have peaks as large as the unmodified stage.

Scenario A was first revised; the Sound Pressure Levels are obtained at supposed receptor points in a location with x of 5.48 m, y of 1.30 m and z of 1.00, 4.00 and 8.00 m. A new study was carried out only considering the most significant parameters with a greater range. On that occasion, considering the three proposed scenarios.

Fig. 6 shows the Sound Pressure Levels (S.P.L.) in a receiving source, considering different panel and ceiling configurations, this for each study frequency. The parameter related to the material of the different ceilings and panels is not significant. Up to this point, two possible sizes have been considered for the panel. Square plates of 0.7 m and 1.1 m side. For subsequent studies, four different measures 0.6, 0.8, 1.0 and 1.2 m of side were proposed. Regarding the absorption coefficients, those corresponding to the Fiberglass Panel will be taken. Studies in all three scenarios were revised.

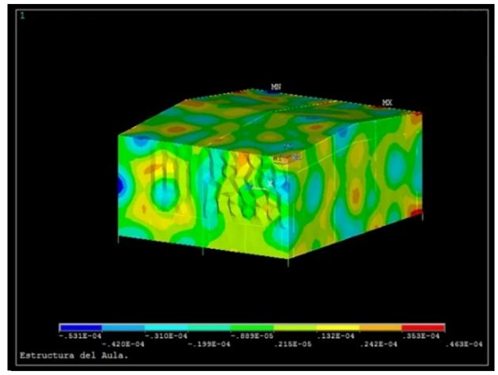
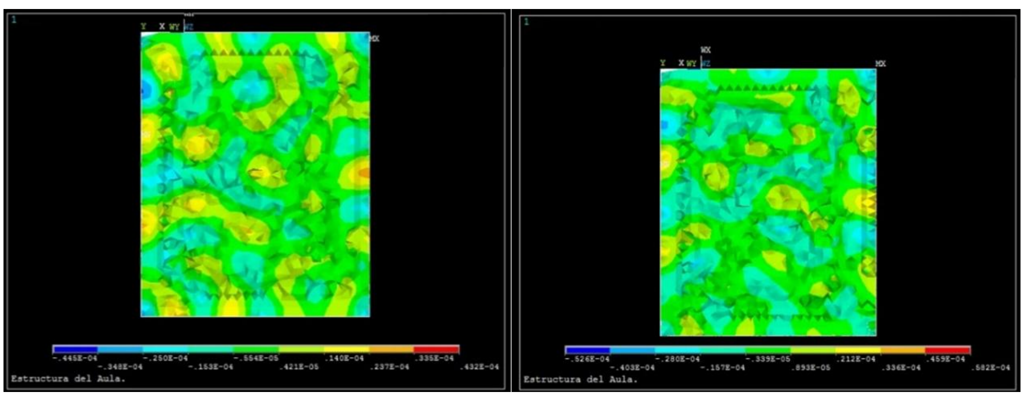


Fig. 4. Pressure Field in the Interface of Fluid-Structure Discreet Model, case with no adequacy

Min Pressure = -0.531E-04 T/m^2 (-0.521 Pa) Loc. at 1.2,2.4,0.0

Max Pressure = 0.463E-04 T/m2 (0.454 Pa) Loc. at 5.3,2.4,0.0



(a) (b)

Fig. 5. Pressure Field at a height of 1.00 m. (a) Case with no adequacy. (b) Case with 4 panels of 1.10 m (2 on the back wall, 2 on the ceiling)

Pressure Range (a) = -0.443E-04 to 0.432E-04 T/m^2 (-0.435 to 0.424 Pa)

Pressure Range (b) = -0.526E-04 to 0.582E-04 T/m^2 (-0.516 to 0.571 Pa)

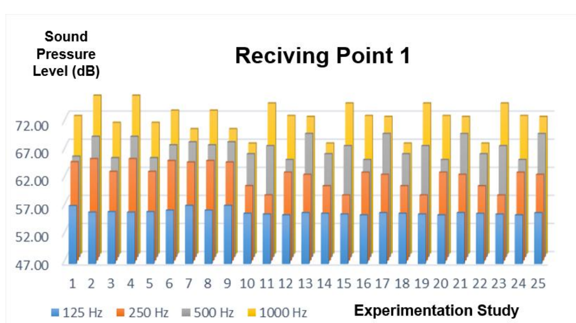


Fig. 6. Sound Pressure Level (S.P.L.) in receiving point 1 (y axis), each Experimentation Study (x axis) is a different configuration of size and material of panel. Is revised each frequency (125 in blue, 250 in orange, 500 in gray, 1000 Hz in yellow)

S.P.L. Range = 56.73 dB to 74.53 dB

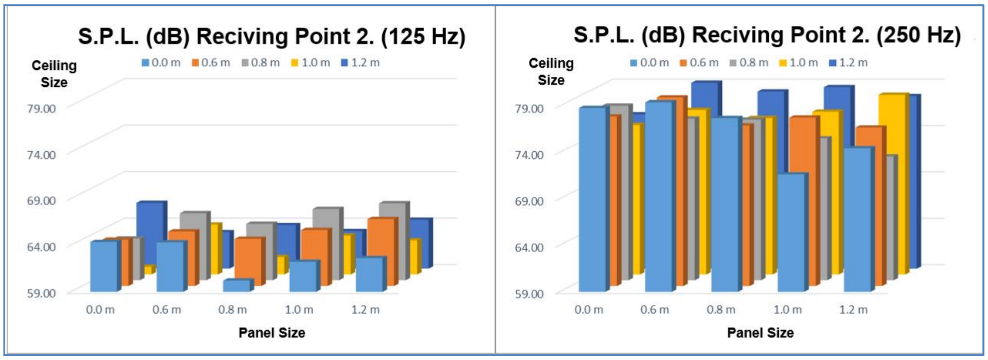
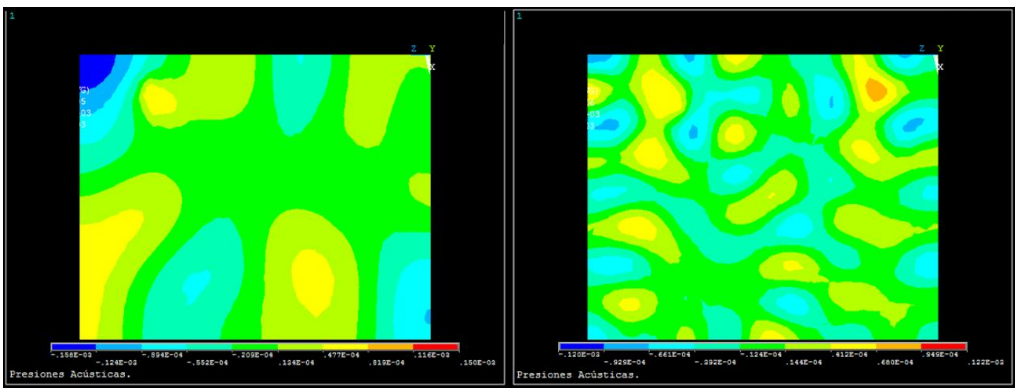


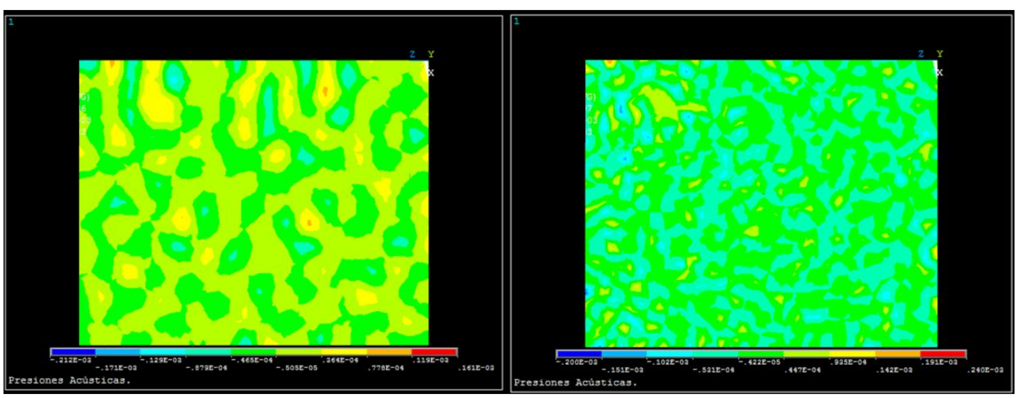
Fig. 7. Sound Pressure Level (S.P.L.) in receiving point 2 (y axis), each set of the horizontal axis is a different configuration of size of panel (x axis) or ceiling (z axis). Is revised two frequencies (125 on the left, 250 Hz on the right)

S.P.L. Range (125 Hz) = 60.24 dB to 66.75 dB

S.P.L. Range (250 Hz) = 71.52 dB to 78.94 dB



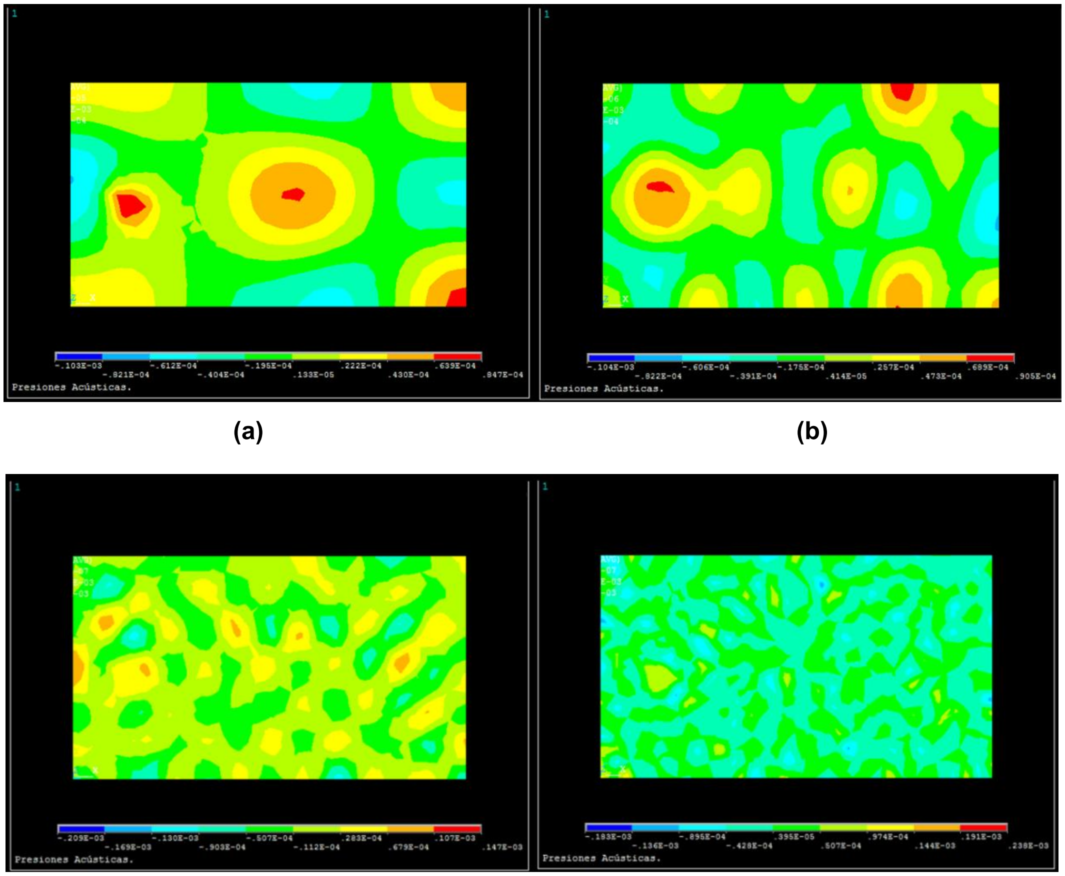
(a) **(b)**



(c) **(d)**

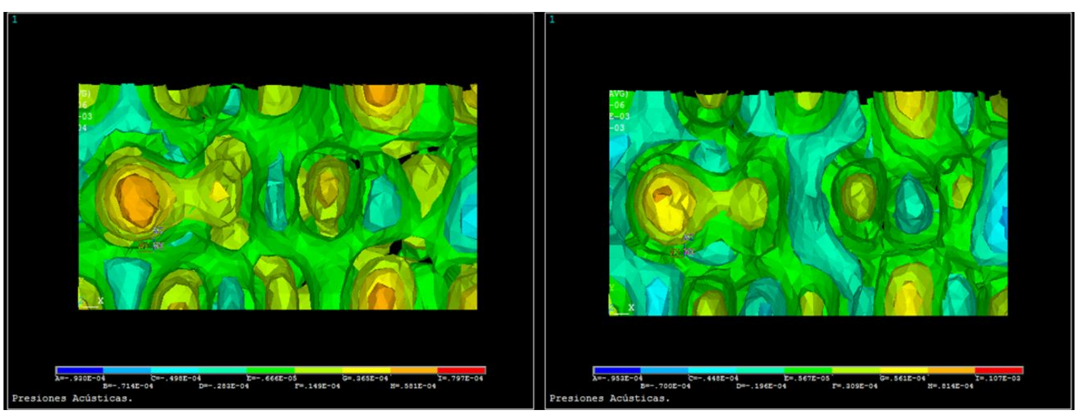
Fig. 8. Pressure Field at a height of 1.00 m, Case with 2 panels of 1.10 m on the back wall (125 Hz (a), 250 Hz (b), 500Hz (c), 1000 Hz (d))

Once the signals were obtained, they were correlated according to the properties of the proposed panel. In Fig. 7, it can been seen the different S.P.L.; varying the size of the panel in one axis and the size of the ceiling in the other. In this particular case, scenario A is shown considering the two frequencies indicated in the graph. The study of the signals was carried out in a similar way in the other scenarios.



(c) **(d)**

Fig. 9. Pressure Field at a distance of 4.00 m through the z-axis, Case with 2 panels of 1.10 m on the back wall (125 Hz (a), 250 Hz (b), 500 Hz (c), 1000 Hz (d))



(a) (b)

Fig. 10. Pressure Field at a distance of 4.00 m through the z-axis. (a) Case with no adequacy. (b) Case with 4 panels of 1.10 m (2 on the back wall, 2 on the ceiling)

Pressure Range (a) = -0.920E-04 to 0.797E-04 T/m^2 (-0. 0.903 to 0.782 Pa)

Pressure Range (b) = -0.952E-04 to 1.070E-04 T/m^2 (-0.934 to 1.050 Pa)

Fig. 8 shows the pressure distribution at the different frequencies, in this case the observed scenario is C, which is when the focus is closest the door. Each quadrant of the image shows the same scenario by modifying the frequency; fig. 8 (a) 125, (b) 250, (c) 500 & (d) 1000 Hz.

On the other hand, Fig. 9 shows scenario B, with a longitudinal section in the location distance of the focus. Again, each quadrant corresponds to a frequency: Fig. 9 (a) 125, (b) 250, (c) 500 & (d) 1000 Hz. Both this image (Fig. 9) and the previous one (Fig. 8) are results of the distribution under normal conditions, without any simulated improvement.

Fig. 10 shows the isosurfaces of pressure distribution considering the same focus location, but varying the improvements, having in fig. 10 (a) the condition without improvement and in (b) a simulated adequacy.

4. CONCLUSION

When deciding the size of the finite element, it is important to notice the limitations that may appear in acoustic analysis with harmonic sources. By seeing the images of pressure distributions (Fig. 8 and Fig. 9), it can be noticed that, as the frequency increases, the pressure peaks get closer, which implies a decrease in the wavelength. If the finite element is too large, it will not be able to calculate the pressure behavior correctly. This limited the frequencies which the analyzes were performed, making it impossible to perform them with high frequencies such as 2,000 and 4,000 Hz.

After reviewing the possible arrangements regarding the location of panels and ceilings, it is concluded that the location within the surface on which they are installed is not a decisive factor. In other words, if we focus on a wall, or roof slab, the difference between doing it in the center or at a certain distance from its edge will not impact the final results. On the other hand, the size of the panel or ceiling represents a more important impact talking about obtaining results.

A couple of material options were modeled. It is true that there was a difference at the obtained pressures, however, the fact of placing a material with a greater absorption than one on surface which panel is located generates more notable differences. In other words, as long as more absorbent materials than the surface are used, there will be a tangible result.

The wave distributions varied depending on frequency; It is noticed that despite having the signals an initial pressure of the same magnitude, the lower frequency had more trouble with propagation in the medium than higher frequencies.

It is possible to perceive a different distribution of acoustic waves with different improvements proposed, being the scenario of the panels with dimension of 1.2 meters the one where the most significant differences are appreciated. It is observed that not only the waves present more stability, but also in general terms there is a higher and more uniform Sound Pressure Level.

It is possible to propose modifications without the necessity of implementing them physically, lowering costs and extra implementation times. Paying attention at the various scenarios and proposals analyzed, and being able to observe the distribution of the acoustic waves, it is seen that there are impacts on the distributions depending on the proposed improvements. This was possible by the implementation of mechanical analysis software.

The author suggest continuing with research in this field, delving into factors that may arise due to various circumstances, such as turbulence or corrections due to large enclosure volumes, accompanied as far as possible with measurements and field experimentation.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Institute of Educational Physical Infrastructure of the State of Querétaro,

IIFEQ. (N.D.). Creation Decree. Santiago de Querétaro, Qro, Mexico: Executive Government of the State of Querétaro. Available:https://www.queretaro.gob.mx/iifeq/content.aspx?q=pvp1botjyj2imbainbj6scfj2fgzyck9

2. Standards and Specifications for Studies, Construction Projects and Installations. Habitability and Operation. Acoustic Conditioning. Mexican Institute of Educational Physical Infrastructure (INIFED); 2011.
3. Álvarez-Morales L, Molina-Rozalem JF, Girón S, Alonso A, Bustamante P, Álvarez-Corbacho A. Virtual reality in church acoustic: visual and acoustic experience in the cathedral of seville, Spain. 24th International Congress on Sound and Vibration. London, England; July 23-27, 2017.
4. Boschi CE. Method for measuring reverberation time in rooms. Leonardo Project. 2008;3(1).
5. Pérez-Egea A, Jiménez LL, Martínez EJ, Castro E. Procedure for analysis and improvement of intelligibility in teaching spaces. 23rd International Congress on Project Management and Engineering. Malaga, Spain; July 10-12, 2019.
6. Díaz-Chyla A, De La Prida D, Pedrero A, Navacerrada MA. The increase in airborne noise insulation of the façade of the classrooms and its effect on the intelligibility of the oral message. XI Ibero-American Congress of Acoustics. Cadiz, Spain. October 24-26, 2018.
7. Turón IA. Acoustic measurements in schools with normally hearing and hearing impaired students. Thesis, School of Engineering and Architecture, University of Zaragoza, Zaragoza, Spain; 2017.
8. AEMPPI Ecuador. (September 7, 2020). Dangers of Noise and its Effects on our Health; 2018. [Online]. Available:https://www.elsevier.com/es-es/connect/actualidad-sanitaria/efectos-negativos-del-ruido-y-su-repercusion-en-nuestra-salud.
9. Cravero GA, Ferreyra SP, Flores MD, Budde L, Longoni HC, Ramos OA, Tommasini FC. Measurement and simulation of reverberation time and other acoustic parameters of classrooms. Computational Mechanics. Mendoza, Argentina. November 19-22, 2013; XXXII.
10. Ferreyra SP, Cravero GA, Flores MD, Budde L, Longoni HC, Ramos OA, Tommasini FC. Modal analysis of university classrooms. Computational Mechanics. Mendoza, Argentina. November 19-22, 2013;XXXII:3978-3993.
11. Montoya Morado E. Improvement of acoustic comfort through implementation of new processes and constructive forms. Master's thesis, Faculty of Engineering, Autonomous University of Querétaro, Querétaro, Qro, México; 2015.
12. Del Rey R, Alba J, Crespo JE, Fontoba J. Proposal of light solutions for acoustic insulation to airborne noise based on sheep wool and green composites. 48 Spanish Acoustics Congress, Iberian Acoustics Meeting. Polytechnic University of Valencia; 2017.
13. Postma BNJ, Katz BFG. Acoustics of notre-dame cathedral of Paris. 22nd International Congress on Acoustics. Buenos Aires, Argentina; September 5-9, 2016.
14. Godoy Lara H. Thermal, acoustic and mechanical characterization of an ecological cellular mortar. Master's thesis, Faculty of Engineering, Autonomous University of Querétaro, Querétaro, Qro, México; 2014.
15. Cobreros Rodríguez C. Prefabricated thermo-acoustic panels for industrialized houses made from cereal straw and stabilized Earth. Doctoral thesis, Faculty of Engineering, Autonomous University of Querétaro, Querétaro, Qro, México; 2015.
16. Gurtin M. An introduction to continuum mechanics. Academic Press; 1981.
17. Hartmann WM. Principles of musical acoustics. New York, USA: Springer; 2013.
18. Belendez A. Acoustics, fluids and thermodynamics. Alicante, Spain: Department of Systems Engineering and Communications, Polytechnic University School, University of Alicante; 1992.
19. CANAIVE. (2012, February 8). CANAIVE presents the results of the study 'how tall is the Mexican People?'. Health Movement, Mexico Moves. [Online].

    Available:https://movimientosalud.wordpress.com/2012/02/08/presenta-la-canaive-los-resultados-del-estudio-cuanto-midemexico/#:~:text=la%20altura%20promedio % 20of% 20las, the% 20zone% 20center% 20of% 2072.37

20. Recuero López M. Architectural acoustics, practical solutions. Madrid, Spain: Editorial Paraninfo; 2000.

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