Journal of University of Babylon for Engineering Sciences, Vol. (26), No. (6): 2018.

Investigation of Sound Transmission Loss Through Sandwich Panel with Foam Core

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Abstract

In the past years, customer and consumer request are increased for performance sound. Where vibration and noise characteristics are made of important design criteria. The vibro- acoustic behavior is considered in the composite sandwich, important research topic to provide a suitable design with consumer requirements.

The sound intensity method is widely using to measure the sound transmission loss between two rooms. This method are used with a composite materials, that are consist of two steel layers between them one layer for core. This paper provides a brief description of the sound intensity method and it is depended on ISO140[1]. Finite Element Method (FEM) are used to comparison with experimental results.The core of different thickness was used to study its effect on acoustic insulation. The experimental and theoretical results are shown, that the value of sound transmission loss are increased by rates of 6dB when the core thickness is doubled .

Keywords: Sound intensity method, Sound Transmission Loss (STL), Sandwich Panel, Vibroacoustic analysis.

LIST OF SYMBOLS

Symbol	*Definition*	*Dimensions*	*Units*
c	Speed of sound	LT^{-1}	m/s
p_o	Reference sound pressure.	FL^{-2}	pa
p	sound pressure	FL^{-2}	pa
S_w	Area of the common wall	L^2	m^2
S_2	total surface area of receiving room	L^2	m^2
L_{P1} and L_{P2}	average sound pressure levels	-	dB
L_{I1} and L_{I2}	average sound intensity	-	dB
$\Pi_{incident}$	Intensity incident on wall	MT^{-3}	w/m^3
$\Pi_{transmitted}$	Intensity incident on wall	MT^{-3}	w/m^3
α_2	absorption for receiving room	M	1/m
ρ	Mass per unit area	ML^{-3}	kg/m^3
STL	sound transmission loss	-	dB

1. Introduction

Weight reduction is one of the main design drivers of modern engineering and transport structures for aerospace and automotive applications. In this context, the sandwich design principle is playing a major role, as it allows for much higher weight-specific bending stiffness compared to a monolithic structure. A sandwich structure typically consists of two thin and stiff skins, separated by a lightweight cellular core. But lightness this sandwich panel, made it tends to cause unwanted noise.

Kwanju Kim *et.al.*,[2], proposed a prediction method of the STL of the aluminum extruded panel when it was used the finite element analysis and the commercial vibroacoustic program MSC ACTRAN, the results from FEM analysis are compared with those from sound intensity experiments based on ASTM E2249-02. for obtain the most accurate analysis results, it was applied the boundary conditions of finite element model closer to the real situation. The specimen in the experiment was placed in the test section by 12 clamps and the boundary was sealed with clay to prevent leakage of sound. 4 boundary condition were used , clamped-clamped, clamped-free, free-clamped, and finally free-free. This a study was founded, the insulation characteristics could be precisely predicted if accurate cross-sectional shape and the material properties were provided. Because fabricating extruding panels costs much, proposed vibration and sound analyzing method will be useful when predicting the insulation performance.

Edwin *et.al.*,[3] , applied the hybrid method to study sound transmission through a wall in between two rooms. It was depended of a hybridization of displacement- based and energy-based modeling, multiple types walls were used in this test, such as, (gypsum blocks, thicker construction wall and double glass). This hybrid method have been a good, due when the laboratory results have been compared with the computational results, it was a good results.

Raef Cherifa and Noureddine Atalla [4], presented a detailed experimental validation of a general laminate model to predict the vibroacoustic behavior of flat sandwich-composite panels. The accuracy of the model was investigated from a thin and a thick sandwich panel, it were used in this validation, a thin panel representative of a trim panel and a thick panel representative of a skin or floor panel. Both are of a honeycomb (HC) core construction. Several indicators were compared including the structural wavenumber, modal density, damping loss factor, radiation efficiency, and sound transmission loss. That the model was predicted very well the wavenumber (dispersion curves), the modal density, and the radiation.

MP Arunkumar *et.al.*,[5], studied the sound transmission loss in the cores, that it was using in aerospace engineering applications such as honeycomb, triangular, trapezoidal, cellular, zed, aluminum foam and rohacell foam with aluminum, titanium and epoxy carbon laminate face sheet. 2D FE model was used for analyzing the free and forced vibration response of the sandwich panel and the calculated vibration response was given as an input to Rayleigh integral in order to obtain the sound transmission loss characteristics. It had been studied the effect of (face and core) thickness the honeycomb core sandwich panel on sound transmission loss and it have been able to use the cell size as the parameter to reduce the weight without affecting the sound transmission loss. It was noticed in foam core panel, that the effect of material on sound transmission loss is significant and this can be controlled by varying the density of foam for various material sheet to keep the sound transmission loss in desirable level.

There are many method are applied to study acoustic behavior in sandwich panel. The sound intensity method is widely using to measure the sound transmission loss between two rooms and this method was depended on ISO140[1]. In this work are studied the influence of the thickness layer of foam and air gap layer between two sandwich on sound transmission loss STL.

2. Theory

2.1 Sound Intensity Method.

In this method two rooms are used, the first room (source room) are reflective chamber. While the second room (receiving room) are semi –anechoic[6].

The STL of each sample was calculated using:

$$STL = L_{p1(source\ room\ )} - L_{I2(receiving\ room} - 6 \tag{8}$$

Where $L_{p1(source\ room\ )}$ is the average sound pressure level measured in the source room, and $L_{I2(receiving\ room}$ is the average intensity measured in the receiving room. For each sample, average STL values are calculated by averaging the results from the three separate tests [7] .Shown Figure (1)

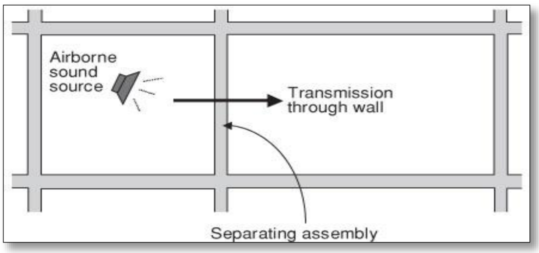


Figure (1): Paths for Sound Transmission [8].

2.2 Finite Element Analysis

The Finite Element Method (FEM) is used in this study to conduct sound analysis for sandwich panel, and study the properties of sound waves resulting from the vibration of sandwich panels. In the sound analysis, modeling is done for (Sound pressure in liquid for different frequencies, particle velocity, sound pressure level, attenuation, radiation and dispersion of sound waves etc...). In the analysis, acoustics are taken into account coupling structure reaction with liquid [9].

2.2.1 Geometrical and Material Properties of Acoustic Room

In this paper, two acoustic rooms are designed. A window is putted between the two rooms. The first room is the larger (source room) and the second room is the smaller (receive room), as shown in Figure (2).

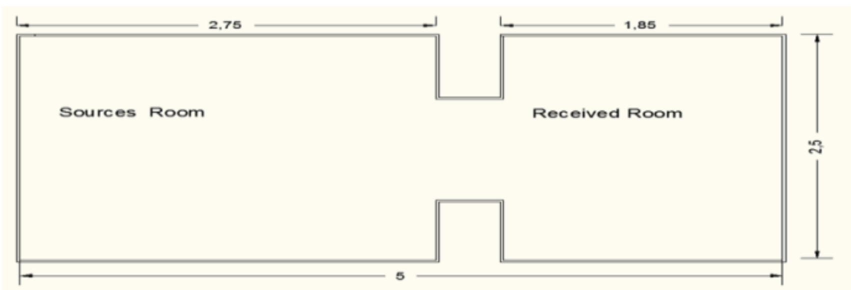


Figure (2): Rooms Acoustic. All Dimension in m.

The engineering characteristics and physical parameters of the models are as follows:

1- Skins material: each layer for the skin has thickness (0.5) mm, density 2800 kg/m3, Young Modulus of elasticity 198 GPa, poison ratio 0.29. The parameters were taken from standard ASTM A525 Galvanized Steel.

2- Core material: the polyurethane (PU) foam had thickness (5o-100) mm, density 40±2 kg/m^3 , Young Modulus of Elasticity (E_1 = 0.21, E_2 = 0.205, E_3 = 0.32) Mpa, Poisson ratio ν_1=0.18, ν_2=0.2, ν_3= 0.33. ASTM D1621-04.

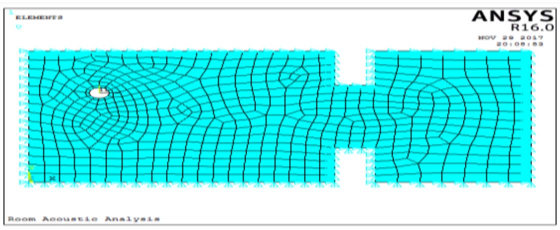
3- Air media in the source room: the air characteristics of the first room (source room) consist of density 1.12 kg/m3, sound speed 343 m/s.

4- Air media in the receive room: the air characteristics of the second room (receive room) consist of density 1.12 kg/ m3, sound speed 343 m/s.

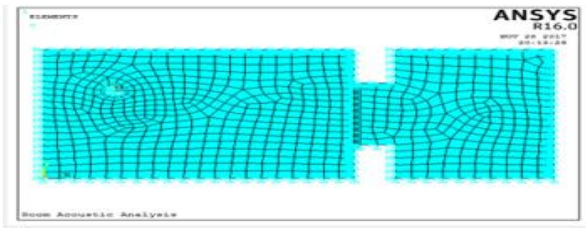
The Beta absorption should be between 0 – 1, where a coefficient of 0 indicates none of the sound is absorbed, and a coefficient of 1 indicates that 100% of it is absorbed. The sound absorption coefficient in two rooms are differed with the band frequency, ISO140 [1].

2.2.2 Boundary Condition

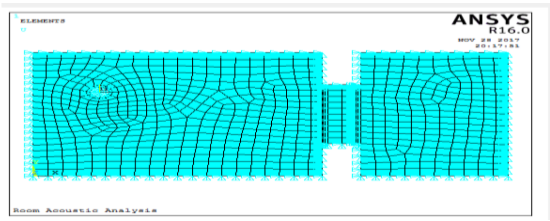
Boundary condition of all models clamped from all sides (Constrain all displacements to zero at the walls). Shown in Figure (3).



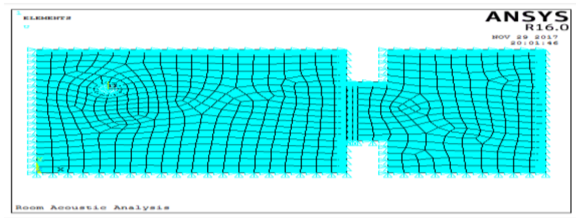
Case (1)



Case (2)



Case (3)



Case (4)

Figure (3): Boundary Condition of all Models of Current Work.

2.2.3 Element Type

Are applied four ANSYS element types are used for in the acoustic analyses:
1-Element (FLUID29). 2-Element (FLUID30).
3-Element (FLUID129). 4-Element (FLUID130**).** [10], shown Figure (4).

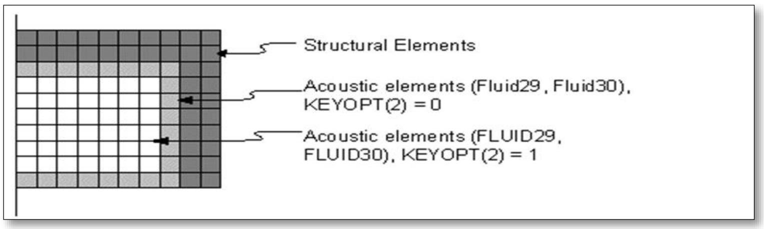


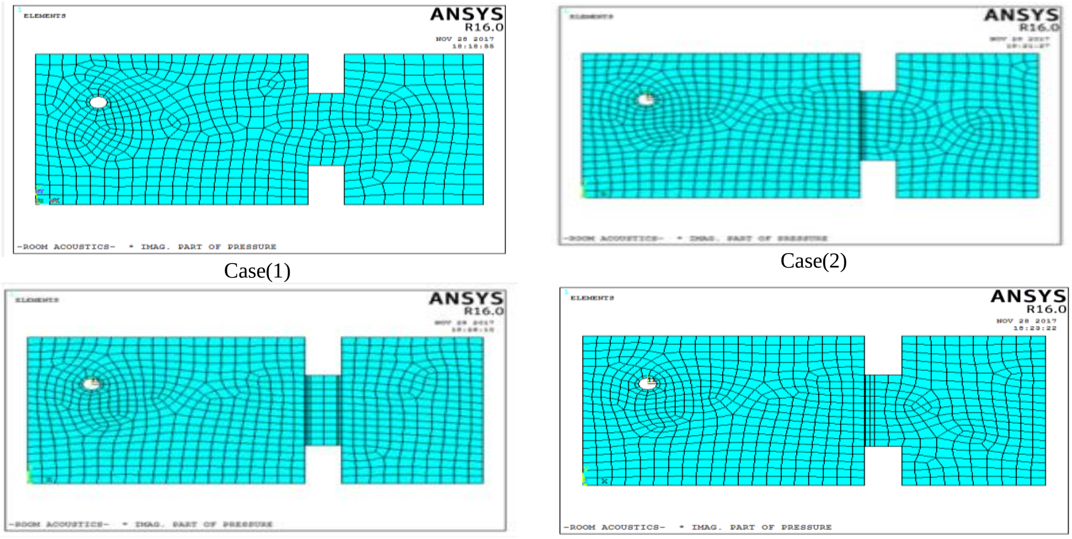
Figure (4): 2-D Acoustic Model [11].

2.2.4 Mesh Convergence

Four cases study are applied, as following:

1- Open the Partition between two rooms.
2- Closed the Partition between two rooms by one sandwich (5) cm thickness core.
3- Closed the Partition between two rooms by two sandwiches (5) cm thickness core.
4- Closed the Partition between two rooms by one sandwich (10) cm thickness core.

FEM models for room acoustic are shown in Figure (5) .



Case(1) Case(2) Case (3) Case (4)

Figure (5): Finite Element Models of rooms acoustic.

3. Experimental work

3.1 Test Facilities (Sound Intensity Method)

The sound transmission loss (STL) was measured by used sound intensity method. Two rooms are used in this method, the first and larger room was called a source room and the second and the smaller room was called received room. The test procedure is based on international organization for Standardization ISO140[1]. As Shown in Figure (6).

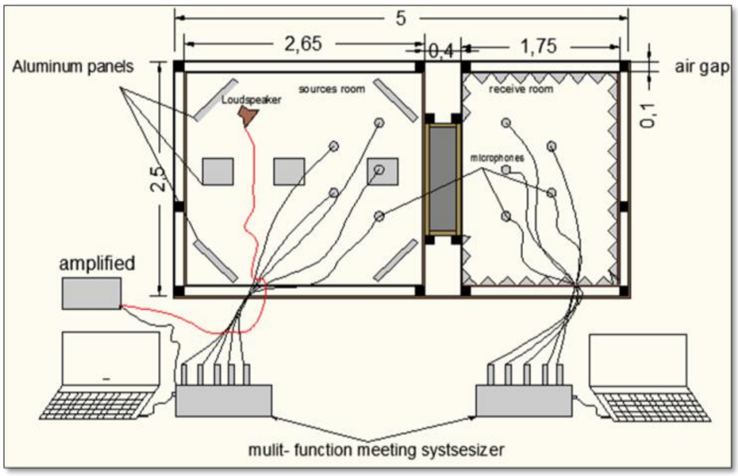


Figure (6): Design of Test Room for Transmission Loss (all Dimensions m).

The two horizontally adjacent rooms are used. the two rooms have the minimum flanking sound transmission. the sound transmission path between the two rooms is directly through the specimen ISO140[1]. Two rooms are made from wood plates installed on iron structures (box iron section 2") and (box iron section 4") pillars at each building corner, between each the two woods plates (4mm) thickness, the air layer (100 mm) thick to increase the sound insulation of the rooms outer perimeter.

In sources room are distributed reflective aluminum panels in all corners, and in addition, the convex reflective panels are suspended on the ceiling. Loudspeaker is installed in one of the corner of the source room to amplify the sound source; the floor of the source room is covered with layers of aluminum panels. As shown in Figure (7).

In the received room all the walls and the floor, it is covered by eggs plates, the floor of the received room was covered by rubber plates to increase sound absorption in addition to egg layers. The egg layers help absorb the acoustic waves that reach the room it makes semi-echo room. Five microphone are placed in each room and the distance between each microphone and each wall is (0.5m). The height of the microphone on the ground is more than (0.7m), shown in Figure (8). ISO140[1] . In the middle of the wall connecting the two rooms is window where the samples are tested. All the samples are dimensions (950 *1300) mm. ISO140[1] .

The samples are supported along the edge by using the bolt (10 mm diameter and 150 mm long), it is used the same torque to tighten the bolts by mechanical bolt fasteners with the addition of putty around the rim to minimize the leakage of sound through the sample.

(a) (b)

Figure (7): Design Rooms Test:(a) Receiving Room.(b)Source Room.

Microphones   Mulit- function meeting systsesizer.   Loudspeaker   Amplified

Figure (8): The Device Used in The Test.

The (pink noise) sound source was generated through the loudspeaker after amplifying the signal. In order to receive the sound wave transmitted in source room, five microphones were distributed, ISO140[1]. These microphones were connected to the mulit- function meeting systsesizer to collect signals recorded by these clips in one signal. Through the (Spectra plus-SC) program [12]. The signal and the sound pressure measurement of this room are analyzed at different frequencies (0-5000)Hz. In the receiving room also, five microphones are distributed in the same way as and all the microphones are connected to the multi- function meeting systsesizer and from there to the signal analysis. For more information visit the official website (www.spectraplus.com), as shown in Figure (9).

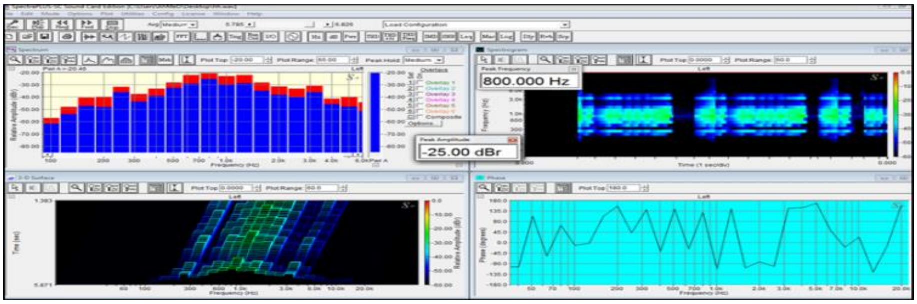


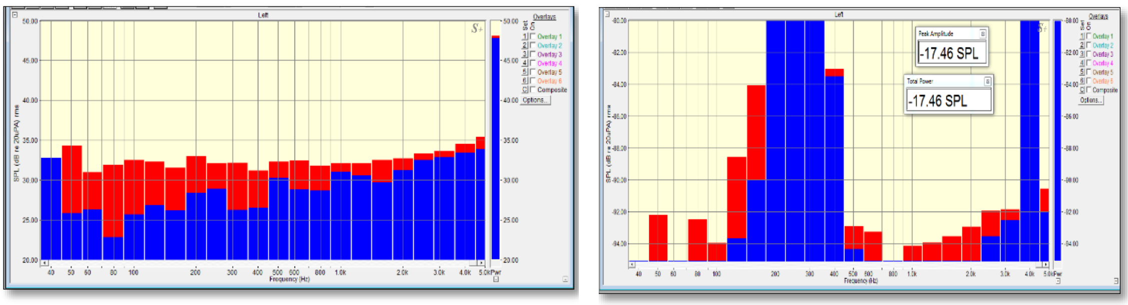
Figure (9): (Spectra plus-SC) Program.

4. Results and Discussions

4.1 (STL) Results Open the Partition Between Two Rooms

Figure (10) represents (SPL) values for experimental testing for one-third octave band.

Table (1) represented the comparison results between theoretical and experimental and error percentage.



(a)   (b)

Figure (10): Experimental (SPL) for Two Rooms When Open the Partition, (a) Resaved Room.(b) Sources Room.

Table (1): Comparison (STL) Results between Theoretical and Experimental and Error Percentage.

One Third Octave Band Frequency(Hz)	*Experimental STL dB*	*Theoretical STL dB*	*Error%*	*One Third Octave Band Frequency(Hz)*	*Experimental STL dB*	*Theoretical STL dB*	*Error%*
100	1	1.13	13	400	10	8.43	15.7
125	2	1.9	5	500	1.9	1.76	7.36
160	7	7.8	11.428	630	-1.3	-1.12	13.85
200	9	10.25	13.89	800	-2.1	-2.24	6.67
250	8	9.2	15	1000	-3.7	-3.25	12.16
315	16	13.75	14.06				

Figure (11) exhibits comparison the experimental and theoretical STL results. The STL values are stable and almost low, because the amount of sound energy are emitted from the source room to receiving room, due the open partition between the two rooms, except for the region with frequencies ranging from (100-200) are noted a rise in the values of STL, this is due to the cavity of the sound emitting chamber .The amplitude values difference is due to the choice a unitary sound source in the numerical model. This does not affect the results in terms of STL **[2---13].**

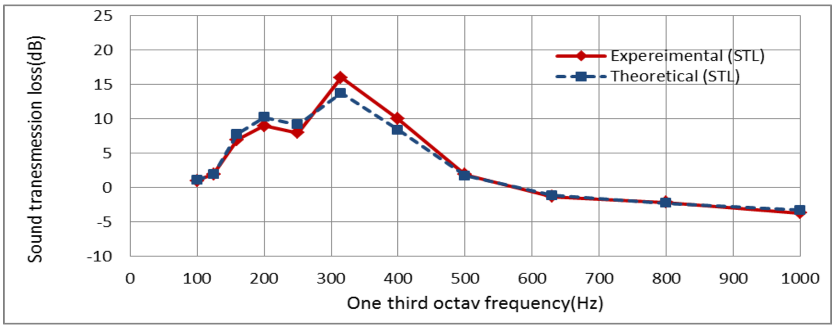
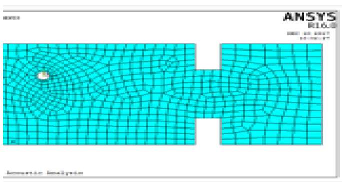


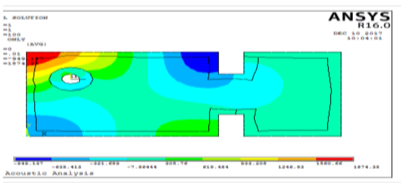
Figure (11): Comparison Theoretical and Experimental STL Results

For Open the Partition Between Two Rooms.

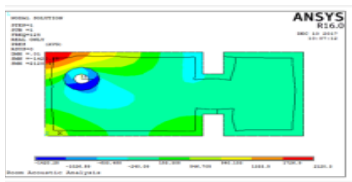
Figure (12) appears the FEM models (mash and sound pressure) inside the rooms at the one third-octave frequency.



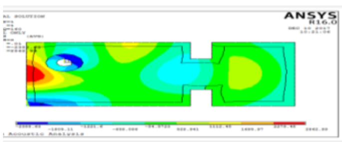
ELEMENT



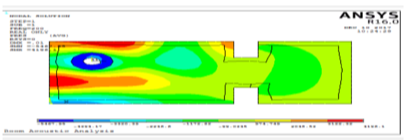
Fn= 100



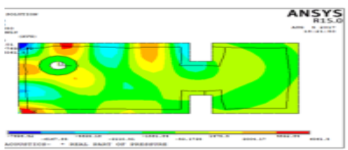
Fn= 125



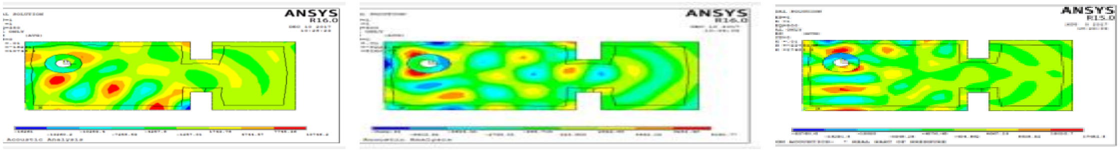
Fn= 160



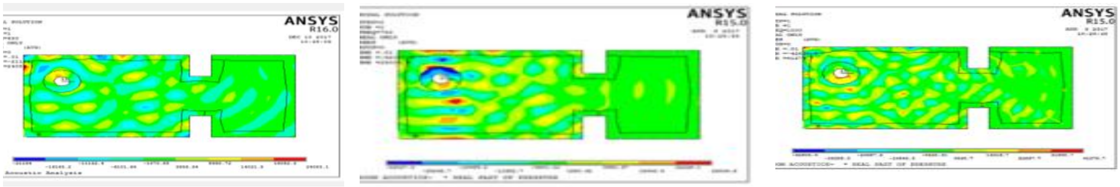
Fn= 200



Fn= 250



Fn= 315 Fn= 400 Fn= 500

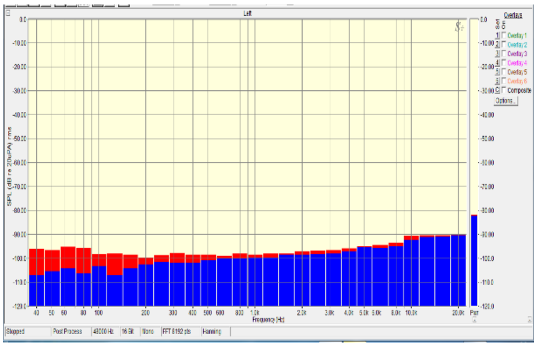


Fn= 630 Fn= 800 Fn= 1000

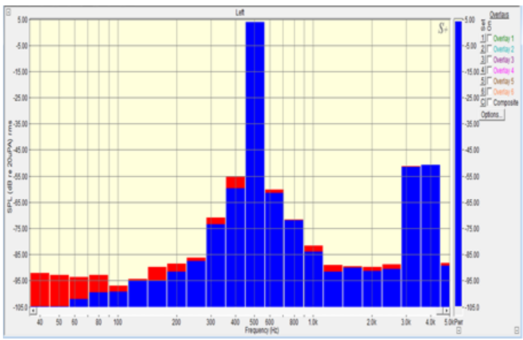
Figure (12): FEM Models Sound Pressure in Rooms at the One-Third Octave Frequency.

4.2 STL Results For One Sandwich Panel 50mm Thickness Core

In this case's study, one sandwich panel are used to close the partial between two rooms. Figure (13) provides (SPL) values for experimental test in one third octave band and for the two rooms .Table (2) represents the comparison results between theoretical and experimental and error percentage.



(a)



(b)

Figure (13): Experimental (SPL) for Two Rooms When close the Partition Between Rooms by One Sandwich Panel 50mm Thickness for Core,(a) Resaved Room.(b) Sources Room.

Table (2): (Experimental and Theoretical) STL Results, closed the Partition Between Two Rooms and Error Percentage.

One Third Octave Band Frequency(Hz)	*Experimental STL dB*	*Theoretical STL dB*	*Error%*	*One Third Octave Band Frequency(Hz)*	*Experimental STL dB*	*Theoretical STL dB*	*Error %*
100	0.6	0.5	16.67	1600	39	36	7.69
200	-5.8	-5.1	12.1	2000	28.7	26.5	7.67
250	8	6.8	15	2500	16.9	18.7	10.65
500	4.5	5.1	13.333	3150	24	21.3	11.25
800	22.88	19.5	14.77	4000	31.5	29.4	6.667
1000	29	32.4	11.72	5000	37	33.1	10.54

Figure (14) represents the comparison (STL) among the experimental and theoretical. The stiffness region is shown at very low frequencies, the resonance panel region are appeared from (200 and 500) Hz, when it is observed decrease in STL value, after that begin mass law region is appeared when an increase STL by rate 6dB for each frequency. At frequency 2500Hz, the coincidence region is shown where a dip in value STL values. At the higher band frequency damping controlled region begin.

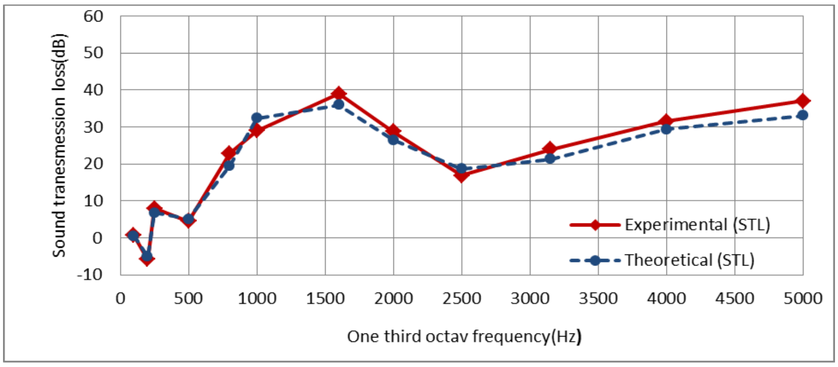


Figure (14): Comparison Theoretical and Experimental STL Results Between Two Rooms for One Third Octave.

Figure (15) appears the FEM models sound pressure inside the Rooms.

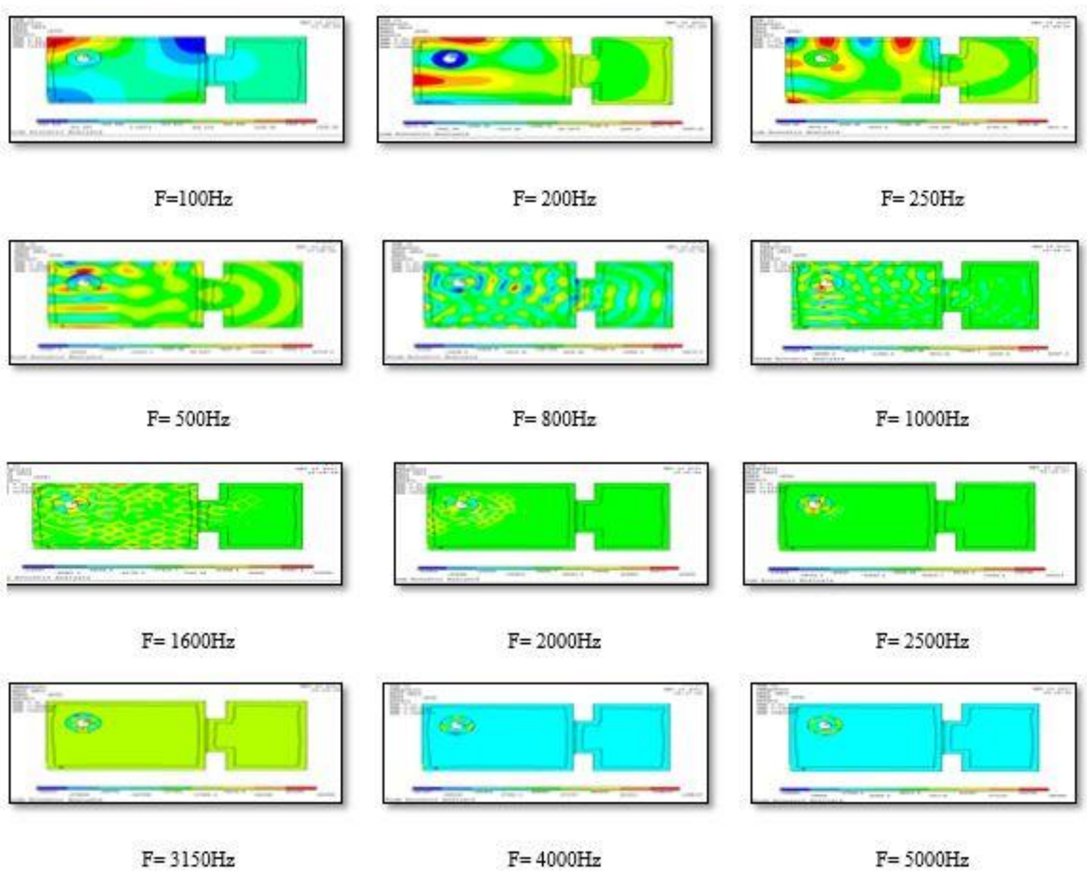
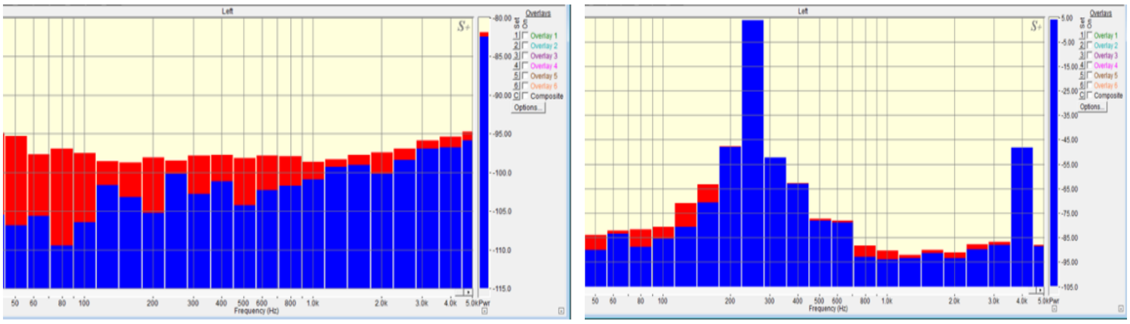


Figure (15):FEM Models (Meshes and Sound Pressure) for Case Study One Sandwich Panel (50) mm for Thickness a Core. Between Two Rooms for One Third Octave.

4.3 STL Results For Closed The Partition by Two Sandwich Panel 50 mm For Thickness Core

Figure (16) provides SPL values of experimental work for one third octave band and two sandwiches panels with 50 mm core thickness are used to close the partition between the two rooms and the air gap are 280 mm between the two sandwiches .

Table(3) represented the comparison results between theoretical and experimental and error percentage.



(a) (b)

Figure (16)): Experimental (SPL) for Two Rooms When Close the Partition Between Rooms by Two Sandwich Panel ,(a) Resaved Room.(b) Sources Room.

Table (3): Comparison (STL) Results Between Theoretical and Experimental and Error Percentage.

One Third Octave Band Frequency(Hz)	Experimental STL dB	Theoretical STL dB	Error%	One Third Octave Band Frequency(Hz)	Experimental STL dB	Theoretical STL dB	Error%
100	2	2.3	15	1600	30	28.75	4.167
200	6	7.1	18.333	2000	18	16.12	10.444
250	9	7.9	12.222	2500	31	34.5	11.3
500	15	13.45	10.333	3150	38	42	10.53
800	21	23.4	11.428	4000	43	48.45	12.6744
1000	24	27.6	15	5000	48	46.25	3.646

Figure(17) shows the comparison among the experimental and theoretical STL result. In STL curve are shown the stiffness and resonance region isn't found, due it appears in very low frequencies, it is out bands frequencies. The mass law region are increased by rate 6dB for each frequency band, but in 2000Hz, the coincidence region is shown where a dip in value STL values, at the mid and higher frequency band, the damping controlled region are appeared. Through the results are shown higher values of sound transmission losses. due to use two sandwich panel between them air gap. The air gap does to increas absorbing the sound energy, due the friction and viscosity in the air layer.and this results are agreed with literature, Moore[14].

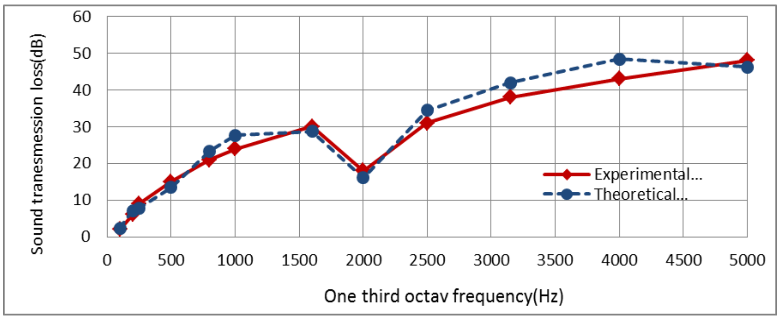
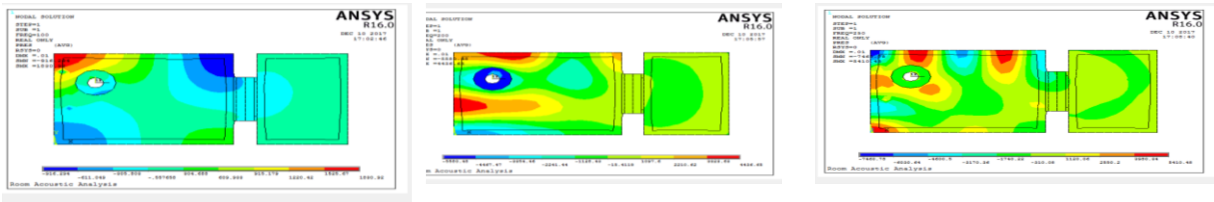


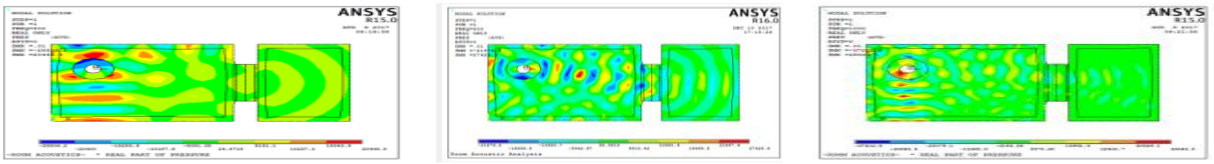
Figure (17) Comparison Theoretical and Experimental (STL), Closed the Partition Between Two Rooms by Using Two Sandwich Panel (50) mm for Thickness for One Third Octave.

Figure (18) appears the FEM models for sound pressure inside the rooms .

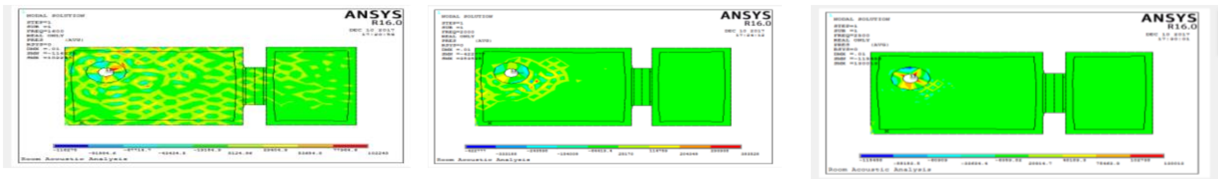


Fn= 100 Fn= 200 Fn= 250

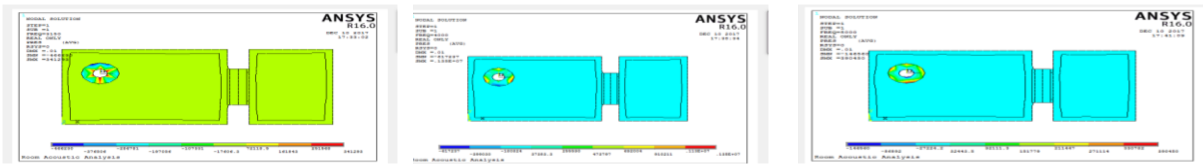
Figure (18) : Continuous Figure



Fn= 500 Fn= 800 Fn= 1000



Fn= 1600 Fn= 2000 Fn= 2500

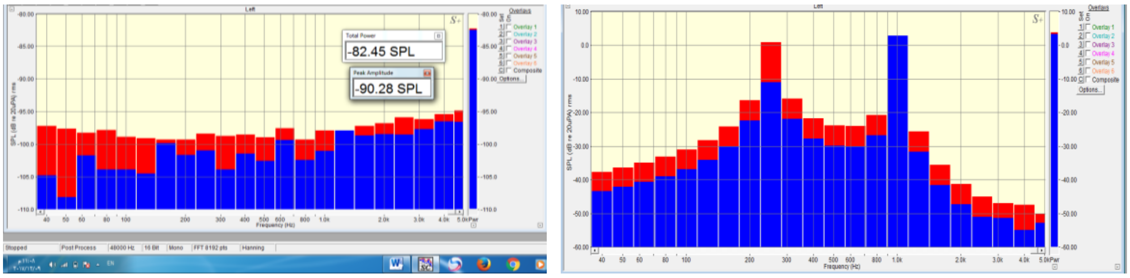


Fn= 3150 Fn= 4000 Fn= 5000

Figure(18): FEM Models Sound Pressurefor Case Study closed the Partition between two rooms by Using Two Sandwich Panel (50) mm for Thickness a Core and air gap Between Them for One Third Octave.

4.4 STL Results For Closed the Partition by One Sandwich Panel 100 mm for Thickness Core

Figure (19) appears the SPL values for experimental work for one third-octave band and one sandwich panel with 100 mm core thickness are used to close the partition between the two rooms.



(a) (b)

Figure (19):Experimental (SPL) for Two Rooms When close the Partition Between Rooms by One Sandwich Panel 100mm Thickness for Core,(a) Resaved Room.(b) Sources Room.

Table (4) provides the comparison results between theoretical and experimental and error percentage.

Table (4): Comparison (STL) Results Between Theoretical and Experimental and Error Percentage.

One Third Octave Band Frequency(Hz)	Experimental STL dB	Theoretical STL dB	Error %	One Third Octave Band Frequency(Hz)	Experimental STL dB	Theoretical STL dB	Error%
100	5	4.4	12	1600	22	20.2	8.18
200	10	8.56	1.44	2000	35	33	5.71
250	13	12.1	6.92	2500	41	38	7.32
500	20	18.4	8	3150	42	46.3	10.23
800	37	35.7	3.714	4000	44.6	47.12	5.65
1000	42	39.4	6.2	5000	48.1	44.8	6.86

Figure (20) shows the comparison STL result among the experimental and theoretical. The STL curve was appeared that the mass law region was increased by rate 6dB for each frequency band. The coincidence region is shown at frequency 1600Hz, where a dip in value STL values.

Figure (5.48) shows the critical frequency value was became in down the frequency band, that due to the effect of using the sandwich panel 50% thickness higher than from using one sandwich panel have 50 mm thickness for core, this is consistent with the literature of Nielsen[15].The value of STL are obtained in this case was higher by 10 dB than the values are obtained when is used one sandwich panel have 50mm thickness core.

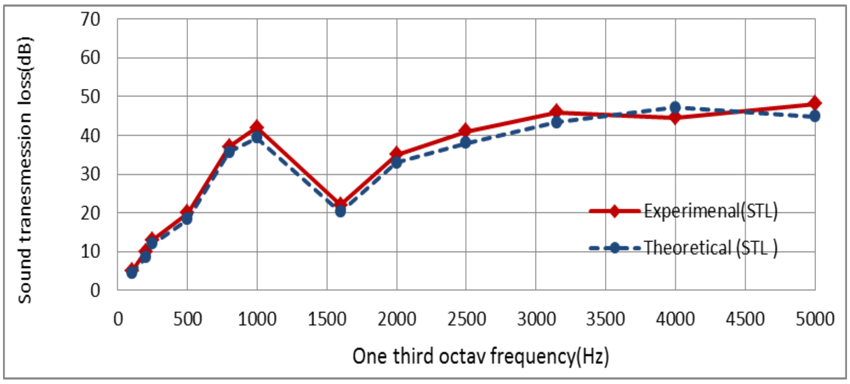


Figure (20): Comparison Theoretical and Experimental, STL Closed the Partition by One Sandwich Panel.

Figure (21) appears the FEM models sound pressure inside the rooms.

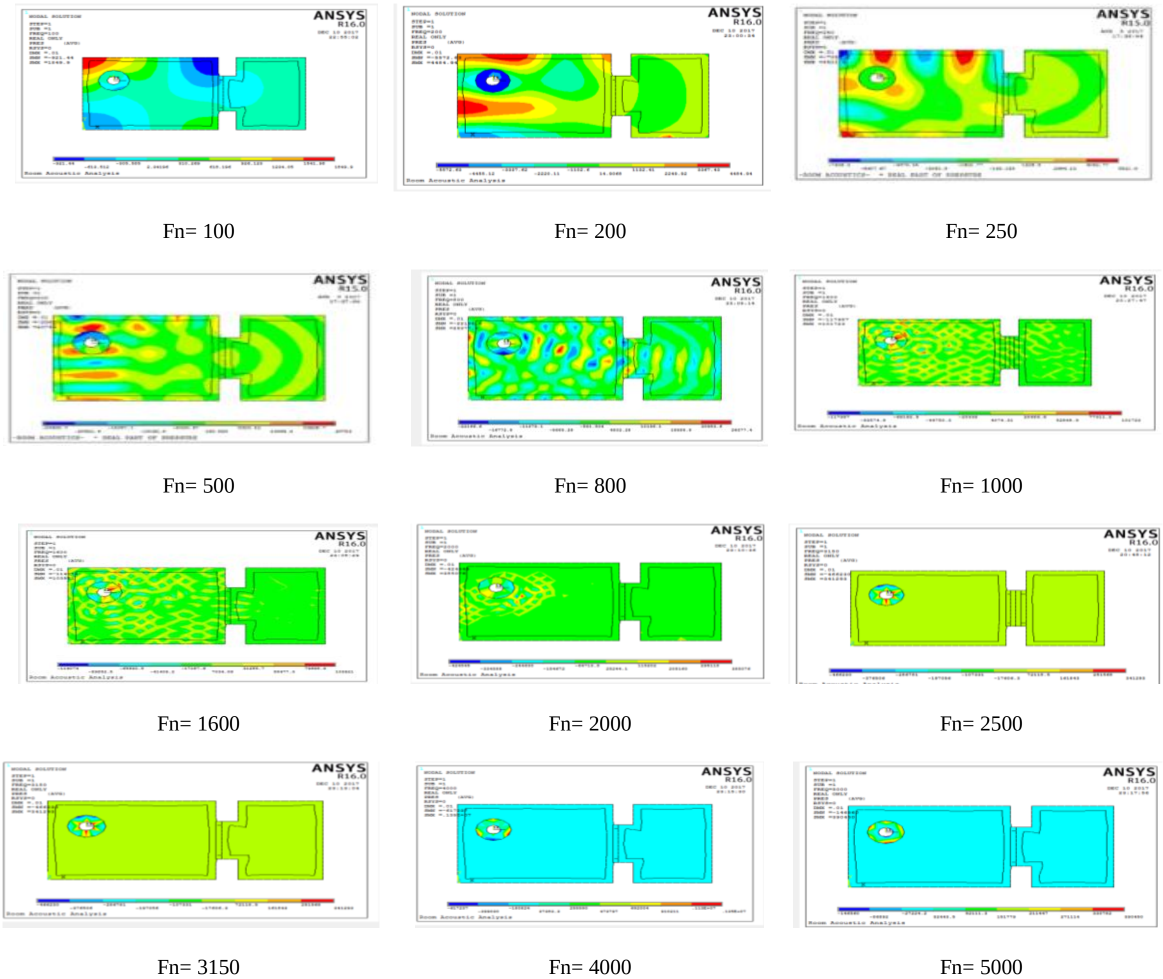


Figure (21):FEM Models Sound Pressure for Case Study Closed the Partition Between Two Rooms by Using One Sandwich Panel (100) mm Thickness Core.

5. Conclusions

Four cases studies to calculate the sound transmission loss between two rooms are applied, the conclusions for this case as flowing:

1 - In open the partial between the two rooms the STL values are stable and low, because most the sound energy transmission from the source to receive room.

2- When closing the parietal by one sandwich panel 50mm thickness core the higher value 39dB was appeared in mass law region, and the stiffness region appeared in very low frequencies, resonance panel region appears from (200 and 500) Hz.

3- The highest values of STL when using two-sandwich panel. This indicates an increase in the improvement of sound loss. And higher value (STL) was 48 dB in damping region.

4 - When using one sandwich panel with 100 mm core thickness. It shows come down in the critical frequency value in the frequency band due**.**

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Journal of University of Babylon for Engineering Sciences, Vol. (26), No. (6): 2018.

التحقيق في خسائر انتقال الصوت من خلال الشطيرة المركبة ذات الرغوة للأساس

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الخلاصة

في السنوات الماضية، تم زيادة طلب العملاء والمستهلكين للحصول على الاداء الصوتي. حيث اصبحت خصائص الاهتزاز والضوضاء من معايير التصميم المهمة. يتم اعتبار السلوك الاهتزاز- الصوتي في الشطائر المركب، موضوع بحث مهم لتوفير تصميم مناسب مع متطلبات المستهلك.

يستخدم طريقة شدة الصوت على نطاق واسع لقياس خسارة انتقال الصوت بين غرفتين. وتستخدم هذه الطريقة مع المواد المركبة التي تتكون من طبقتين من الصلب بينهما طبقة واحدة للأساس. يتم في هذا البحث وصف موجزا لطريقة شدة الصوت التي تعتمد على المعايير البريطانية **.ISO140**[1] استخدمت طريقة العنصر ال محدود FEMمن اجل المقارنة مع النتائج التجريبية .استخدم سمك مختلف لطبقة الاساس لدراسة تأثير ذلك على مقدار خسائر الانتقال الصوتي. وتظهر النتائج التجريبية والنظرية، أن قيمة خسارة الانتقال الصوتي تزداد بمعدلات (6 ديسيبل)، عندما يتضاعف سمك الاساس.

الكلمات المفتاحية: - طريقة شدة الصوت، خسائر الارسال الصوتي، الشطيرة المركبة، تحليل الاهتزاز – الصوتي.