STUDIES AND RESEARCH REGARDING SOUND REDUCTION MATERIALS WITH THE PURPOSE OF REDUCING SOUND POLLUTION

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ABSTRACT

Studies and research regarding sound reduction materials

with the purpose of reducing sound.

Timothy Hawkins

Noise can be defined as unwanted sound. There are many cases and applications that reducing noise level is of great importance. Loss of hearing is only one of the effects of continuous exposure to excessive noise levels. Noise can interfere with sleep and speech, and cause discomfort and other non-auditory effects. High level noise and vibration lead to structural failures as well as reduction in life span. The importance of noise issue could be well understood by looking at regulations that have been passed by governments to restrict noise production in society. Industrial machinery, air/surface transportation and construction activities are main contributors in noise production or "noise pollution". Noise Pollution is not only an annoyance; it is an environmental health hazard. Noise can be found anywhere that life exists, in forests, in the workplace, in homes across America and even under water. A lot of research has been done about noise pollution in the last 40 years, but yet there is still more to learn about how to control and lessen the affects that noise has on human and animal life. Noise control is a major factor in the planning, design, and construction of transportation corridors. Architects, acoustical engineers and transportation planners are searching for creative ways to eliminate or greatly reduce noise levels.

The challenge lies in attaining desired sound levels while simultaneously maintaining or enhancing the visual environment. I will be setting up an experiment to determine what kinds of materials absorb sound waves of varying frequencies most effectively.

Keywords: Unwanted sound, Industrial machinery, Acoustical Engineers, Transportation Planners, Noise Pollution, Noise Control.

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CHAPTER 1

Introduction

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Statement of the Problem

A lot of research has been done about noise pollution in the last 40 years, but yet there is still more to learn about how to control and lessen the affects that noise has on human and animal life. Noise control is a major factor in the planning, design, and construction of transportation corridors. Architects, acoustical engineers and transportation planners are searching for creative ways to eliminate or greatly reduce noise levels. The challenge lies in attaining desired sound levels while simultaneously maintaining or enhancing the visual environment.

I will be setting up an experiment to determine what kinds of materials absorb sound waves of varying frequencies most effectively. My objective is to compare sound reduction effectiveness on different materials under different frequencies in term of Sound Reduction Index(R) and Transmitted coefficient (T).

CHAPTER 2

Noise and Sound

Sound is a form of energy that is transmitted by pressure variations which the human ear can detect. When one plays a musical instrument, say a guitar, the vibrating chords set air particles into vibration and generate pressure waves in the air. [3] A person nearby may then hear the sound of the guitar when the pressure waves are perceived by the ear. Sound can also travel through other media, such as water or steel.

Apart from musical instruments, sound can be produced by many other sources - man's vocal cord, a running engine, a vibrating loudspeaker diaphragm, an operating machine tool, and so on. [6]

Definitions and Fundamental Concepts for Sound and Noise

The ear comprises of three parts: The outer ear, the middle ear, and the inner ear.

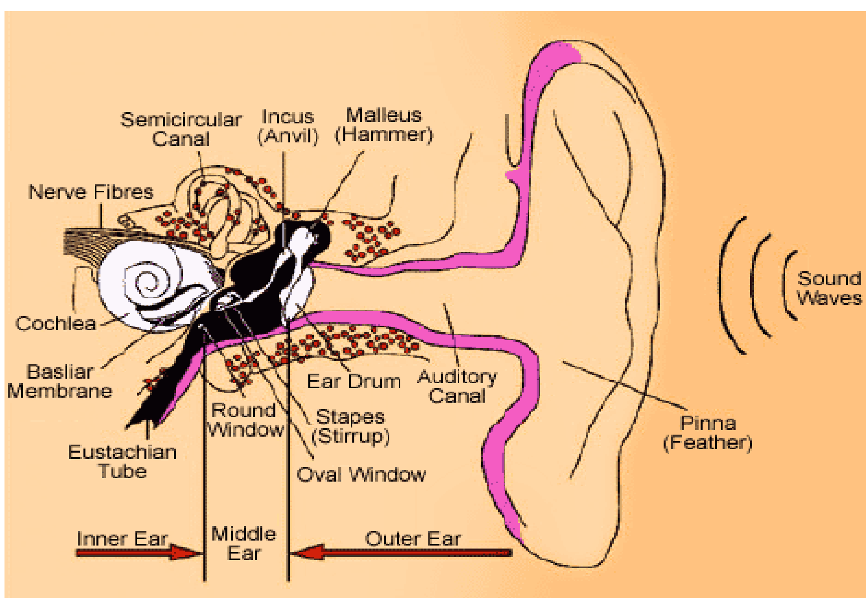

Figure 1 - Perception of Sound - Human Ear

Response to the Human Ear and Noise

Frequency is one of the properties of sound or noise. A sound with a high frequency is said to be high-pitched and a sound with a low frequency is low-pitched There is a remarkably wide range of frequencies and sound pressure levels over which the human ear can detect. The following diagram shows the audible range of a normal human ear.

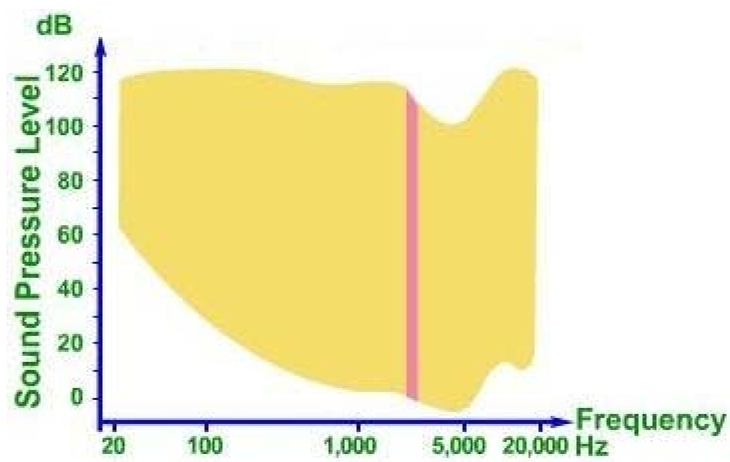

Figure 2 - The audible sound pressure range is from 0 dB to 120 dB.

Human Perception of Noise

It is a theory in psychology that our perception of objects, both visual and auditory, is determined by certain principles. These principles function so that our perceptual worlds are organized into the simplest pattern consistent with the sensory information and with our experience. [1]

In hearing, we also tend to organize sounds into auditory objects or streams and use the principles of grouping to help us to segregate those components we are interested in from others. We are thus able to focus our listening attention to a particular noise source and distinguish an auditory object from the background noise.

The human ears can detect not only changes in the overall sound pressure level but are so sophisticated that they can detect sound, the sound pressure level of which is well below the background noise level.

While there are variations in individual perception of the strength of a sound, studies have shown that to a good approximation, the sound is perceived twice as loud if the sound level increases by 10 dB. Similarly, a 20 dB increase in the sound level is perceived as four times as loud by the normal human ear.

Characteristics of Sound and the Decibel Scale

Sound is the quickly varying pressure wave travelling through a medium. When sound travels through air, the atmospheric pressure varies periodically. The number of pressure variations per second is called the frequency of sound, and is measured in Hertz (Hz) which is defined as cycles per second. [9]

The higher the frequency, the more high-pitched a sound is perceived. The sounds produced by drums have much lower frequencies than those produced by a whistle, as shown in the following diagrams. Please click on the demo button to hear their sounds and the difference in pitch. [9]

Another property of sound or noise is its loudness. A loud noise usually has a larger pressure variation and a weak one has smaller pressure variation. Pressure and pressure variations are expressed in Pascal, abbreviated as Pa, which is defined as N/m^2(Newton per square metre).

Human ear can perceive a very wide range of sound pressure. The softest sound a normal human ear can detect has a pressure variation of 20 micro Pascals, abbreviated as μPa, which is 20×10^{-6} Pa ("20 millionth of a Pascal") and is called the Threshold of Hearing. On the other hand, the sound pressure close to some very noisy events such as launching of the space shuttle can produce a large pressure variation at a short distance of approximately 2000 Pa or 2×10^{9} μPa. [1]

The following table illustrates sound pressure level of the above events expressed in Pa and μPa.

	Sound Pressure expressed in	
	Pa	μPa
Softest Noise just Heard by a Human Ear	20×10^{-6}	20
Launching of the Space Shuttle	2,000	2×10^{9}

Figure 3 – Sound Pressure Level Expressed in Pa

To express sound or noise in terms of Pa is quite inconvenient because we have to deal with numbers from as small as 20 to as big as 2,000,000,000. [2] The following table shows some common sound or noise in terms of μPa:

Source of Sound/Noise	Approximate Sound Pressure in μPa
Launching of the Space Shuttle	2,000,000,000
Full Symphony Orchestra	2,000,000
Diesel Freight Train at High Speed at 25 m	200,000
Normal Conversation	20,000
Soft Whispering at 2 m in Library	2,000
Unoccupied Broadcast Studio	200
Softest Sound Human can Hear	20

Figure 4 – Common Sound or Noise in terms of Pa

A simpler way is to use a logarithmic scale for the loudness of sound or noise, using 10 as the base. The following is a brief introduction of the common logarithm to the base 10.

To avoid expressing sound or noise in terms of Pa, which could involve some unmanageable numbers, the decibel or dB scale is used. The scale uses the hearing threshold of 20 μPa or 20 x 10^{-6} Pa as the reference level. This is defined as 0 dB. Sound pressure level, which is often abbreviated as SPL or L_p, in decibels (dB), can then be obtained using the following formula.

$$\text{SPL (in dB)} = 20 \log_{10} \frac{\text{Measured Sound Pressure}}{\text{Reference Pressure}}$$

Figure 5 – Decibel Formula

In the following chart, some sounds are expressed both linearly in µPa and logarithmically in dB. One can see how the logarithmic scale helps us to handle numbers on a wide scale much more easily.

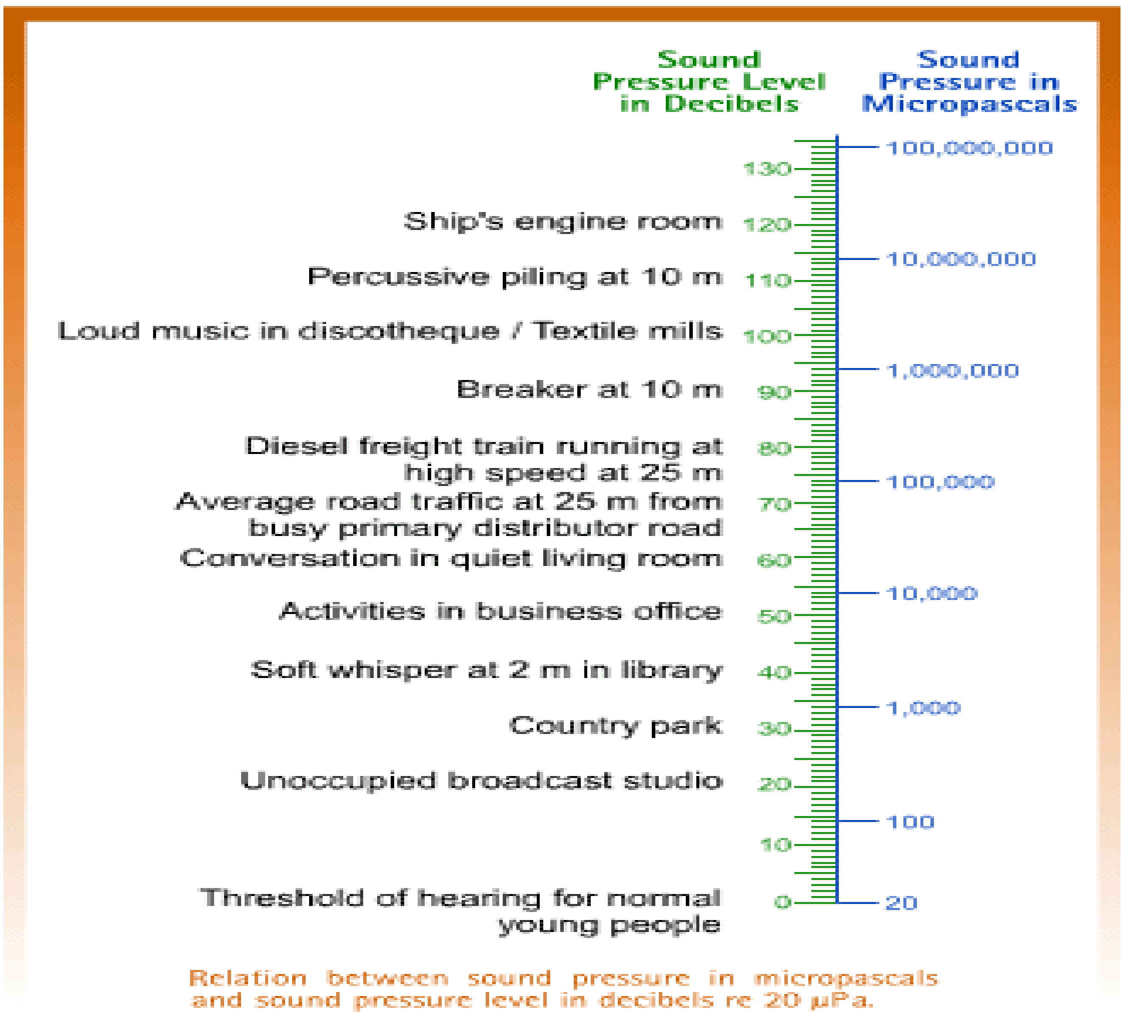

Figure 6 –Relation Between Sound Pressure in Decibels vs Micropascals

One useful aspect of the decibel scale is that it gives a much better approximation to the human perception of relative loudness than the Pascal scale. This is because human ear responds to the logarithmic change in level, which corresponds to the decibel scale. [6]

Adding Sounds or Noises together on the Decibel Scale

In real life, several sources of sounds often occur at the same time. One may be interested to know what results when one sound is combined with another, i.e. the addition of sounds. [10]

Adding 60 apples to 60 apples results in 120 apples. But this is not the case with sounds when they are expressed in decibels. In fact, adding 60 decibels to 60 decibels gives 63 decibels. The following formula explains the general principle of adding sounds on the decibel scale.

$$L_t = 10 \log \left(\sum_{i=1}^{n} 10^{L_i/10} \right) \quad \text{dBA}$$

(Note that L simply replaces L_p in this equation.) Expanding and substituting, we obtain

$$\begin{aligned} L_t &= 10 \log (10^{34.6/10} + 10^{39.8/10} + 10^{54.9/10} + 10^{52.4/10} + 10^{56.8/10} \\ &\quad + 10^{75/10} + 10^{83.2/10} + 10^{81.0/10} + 10^{85.9/10} + 10^{83.4/10}) \quad \text{dBA} \\ &= 89.9 \text{ dBA} \end{aligned}$$

Figure 7 – Formula to add three sounds together in Decibels

Addition of sound levels can also be done simply using the following chart

Figure 8 – Addition of Sound Levels

In using the Chart, two sounds are added together first. The resultant sound is then added to a third sound and so on.

A normal human ear is able to hear sounds with frequencies from 20 Hz to 20,000 Hz. The range of 20 Hz to 20,000 Hz is called the audible frequency range. The sounds we hear comprise of various frequencies. The entire audible frequency range can be divided into 8 or 24 frequency bands known as octave bands or 1/3 octave bands respectively for analysis. A particular sound or noise can be seen to be having different strengths or sound pressure levels in the frequency bands, as illustrated by the following diagram.

One single sound pressure level is often used to describe a sound. This can be done by adding the contribution from all octave bands or 1/3 octave bands together to yield one single sound pressure level.

The response of the ear to sound is dependent on the frequency of the sound. The human ear has peak response around 2,500 to 3,000 Hz and has a relatively low response at low frequencies. Hence, the single sound pressure level obtained by simply adding the contribution from all octave bands or 1/3 octave bands together will not correlate well with the non-linear frequency response of the human ear.

This has led to the concept of weighting scales. The following diagram shows the "A-weighting" scale:

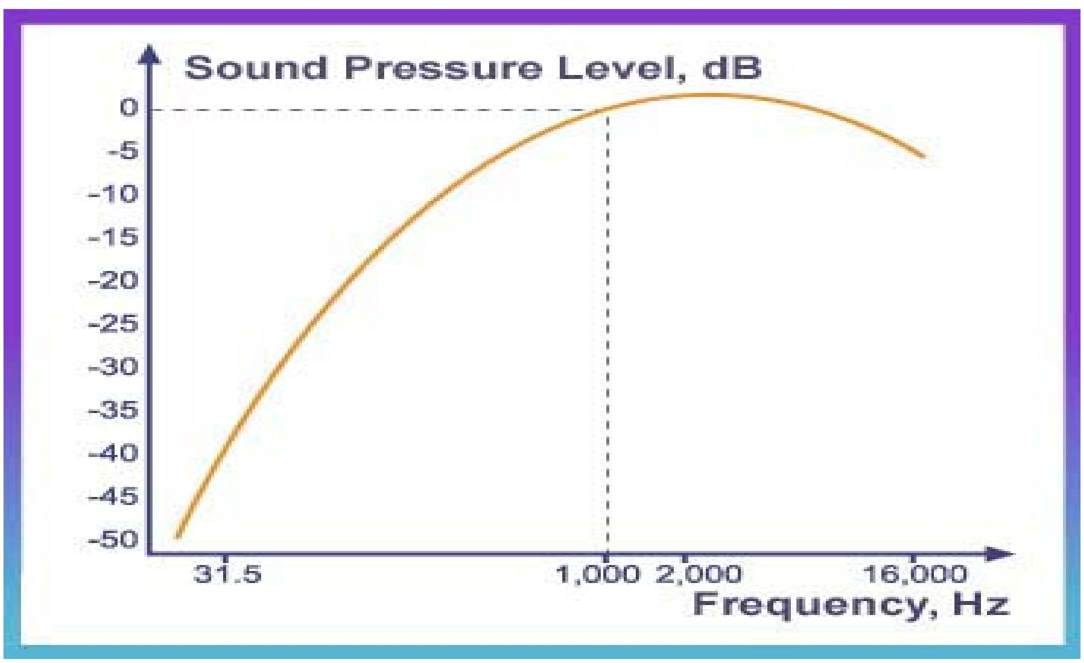

Figure 9 –Weighting Scale

In the "A-weighting" scale, the sound pressure levels for the lower frequency bands and high frequency bands are reduced by certain amounts before they are being combined together to give one single sound pressure level value. This value is designated as dB(A). The dB(A) is often used as it reflects more accurately the frequency response of the human ear. Weighting networks are often incorporated in measuring equipments to give readings in dB(A).

Propagation of Sound

In air, sound is transmitted by pressure variations from its source to the surroundings.

The sound level decreases as it gets further and further away from its source. While absorption by air is one of the factors attributing to the weakening of a sound during transmission, distance plays a more important role in noise reduction during transmission.

The reduction of a sound is called attenuation. The effect of distance attenuation depends on the type of sound sources. Most sounds or noises we encountered in our daily life are from sources which can be characterized as point or line sources. If a sound source produces spherical spreading of sound in all directions, it is a point source. [3]

For a point source, the noise level decreases by 6 dB per doubling of distance from it. If the sound source produces cylindrical spreading of sound as shown in this diagram, such as stream of motor vehicles on a busy road at a distance, it may be considered as a line source. Please click on the demo button to see the details. For a line source, the noise level decreases by 3 dB per doubling of distance from it. [3]

CHAPTER 3

Noise Barriers

A noise barrier (also called a soundwall, sound berm, sound barrier, or acoustical barrier) is an exterior structure designed to protect inhabitants of sensitive land use areas from noise pollution. Noise barriers are the most effective method of mitigating roadway, railway, and industrial noise sources – other than cessation of the source activity or use of source controls.

In the case of surface transportation noise, other methods of reducing the source noise intensity include encouraging the use of hybrid and electric vehicles, improving automobile aerodynamics and tire design, and choosing low-noise paving material. Extensive use of noise barriers began in the United States after noise regulations were introduced in the early 1970s.

Noise barriers have been built in the United States since the mid-twentieth century, when vehicular traffic burgeoned. In the late 1960s, acoustical science technology emerged to mathematically evaluate the efficacy of a noise barrier design adjacent to a specific roadway. By the 1991s, noise barriers that included use of transparent materials were being designed in Denmark and other western European countries. [11]

The best of these early computer models considered the effects of roadway geometry, topography, vehicle volumes, vehicle speeds, truck mix, roadway surface type, and micro-meteorology. Several U.S. research groups developed variations of the computer modeling techniques: Caltrans Headquarters in Sacramento, California; the ESL Inc. group in Palo Alto, California; the Bolt, Beranek and Newman group in

Cambridge, Massachusetts, and a research team at the University of Florida. Possibly the earliest published work that scientifically designed a specific noise barrier was the study for the Foothill Expressway in Los Altos, California. [13]

Numerous case studies across the U.S. soon addressed dozens of different existing and planned highways. Most were commissioned by state highway departments and conducted by one of the four research groups mentioned above. The U.S. National Environmental Policy Act [7] effectively mandated the quantitative analysis of noise pollution from every Federal-Aid Highway Act Project in the country, propelling noise barrier model development and application. With passage of the Noise Control Act of 1972, demand for noise barrier design soared from a host of noise regulation spinoff. By the late 1970s, more than a dozen research groups in the U.S. were applying similar computer modeling technology and addressing at least 200 different locations for noise barriers each year. As of 2006, this technology is considered a standard in the evaluation of noise pollution from highways. The nature and accuracy of the computer models used is nearly identical to the original 1970s versions of the technology. [13]

Sound Attenuation through noise Barriers

The acoustical science of noise barrier design is based upon treating an airway or railway as a line source. The theory is based upon blockage of sound ray travel toward a particular receptor; however, diffraction of sound must be addressed. Sound waves bend (downward) when they pass an edge, such as the apex of a noise barrier. Further complicating matters is the phenomenon of refraction, the bending of sound rays in the presence of an inhomogeneous atmosphere. Wind shear and thermocline produce such inhomogeneities. [16]

The sound sources modeled must include engine noise, tire noise, and aerodynamic noise, all of which vary by vehicle type and speed. The resulting computer model is based upon dozens of physics equations translated into thousands of lines of computer code. Software applications are available which are able to model these situations and assist in the design of such noise barriers.

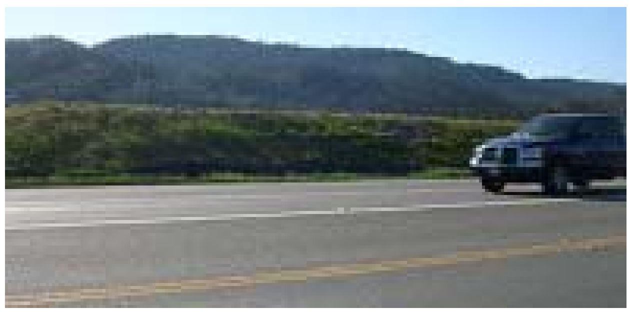

Figure 10 – Noise Barrier berm along Highway 12, Sonoma County, California

Noise barrier earth berm along Highway 12, Sonoma County, California
Some noise barriers consist of a masonry wall or earthwork, or a combination thereof (such as a wall atop an earth berm). Sound abatement walls are commonly constructed using steel, concrete, masonry, wood, plastics, insulating wool, or composites. In the most extreme cases, the entire roadway is surrounded by a noise abatement structure, or dug into a tunnel using the cut-and-cover method. The noise barrier may be constructed on private land, on a public right-of-way, or on other public land. Because sound levels are measured using a logarithmic scale, a reduction of nine decibels is equivalent to elimination of approximately 80 percent of the unwanted sound. [14]

Noise barriers can be extremely effective tools for noise pollution abatement, but theory calculates that certain locations and topographies are not suitable for use of any reasonable noise barrier. Cost and aesthetics play a role in the final choice of any noise barrier. [12]

Normally, the benefits of noise reduction far outweigh aesthetic impacts for residents protected from unwanted sound. These benefits include lessened sleep disturbance, improved ability to enjoy outdoor life, reduced speech interference, stress reduction, reduced risk of hearing impairment, and a reduction in the elevated blood pressure created by noise that improves cardiovascular health. [15]

CHAPTER 4

Studies and Research regarding Sound Attenuation of Sound Absorbing Materials

All materials have some sound absorbing properties. Incident sound energy which is not absorbed must be reflected, transmitted or dissipated. A material's sound absorbing properties can be described as a sound absorption coefficient in a particular frequency range. The coefficient can be viewed as a percentage of sound being absorbed, where 1.00 is complete absorption (100%) and 0.01 is minimal (1%). [4]

Parameters of Sound

Incident sound striking a room surface yields sound energy comprising reflected sound, absorbed sound and transmitted sound. Most good sound reflectors prevent sound transmission by forming a solid, impervious barrier. Conversely, most good sound absorbers readily transmit sound. Sound reflectors tend to be impervious and massive, while sound absorbers are generally porous, lightweight material. It is for this reason that sound transmitted between rooms is little affected by adding sound absorption to the wall surface.

Absorbing Materials

There are three basic categories of sound absorbers: porous materials commonly formed of matted or spun fibers; panel (membrane) absorbers having an impervious surface mounted over an airspace; and resonators created by holes or slots connected to an enclosed volume of trapped air. The absorptivity of each type of sound absorber is dramatically (in some cases) influenced by the mounting method employed. [8]

1) Porous absorbers: Common porous absorbers include carpet, draperies, spray-applied cellulose, aerated plaster, fibrous mineral wool and glass fiber, open-cell foam, and felted or cast porous ceiling tile. Generally, all of these materials allow air to flow into a cellular structure where sound energy is converted to heat. Porous absorbers are the most commonly used sound absorbing materials. Thickness plays an important role in sound absorption by porous materials. Fabric applied directly to a hard, massive substrate such as plaster or gypsum board does not make an efficient sound absorber due to the very thin layer of fiber. Thicker materials generally provide more bass sound absorption or damping. [5]

2) Panel Absorbers: Typically, panel absorbers are non-rigid, non-porous materials which are placed over an airspace that vibrates in a flexural mode in response to sound pressure exerted by adjacent air molecules. Common panel (membrane) absorbers include thin wood paneling over framing, lightweight impervious ceilings and floors, glazing and other large surfaces capable of resonating in response to sound. Panel absorbers are usually most efficient at absorbing low frequencies. This fact has been learned repeatedly on orchestra platforms where thin wood paneling traps most of the bass sound, robbing the room of “warmth.” [14]

3) Resonators: Resonators typically act to absorb sound in a narrow frequency range. Resonators include some perforated materials and materials that have openings (holes and slots). The classic example of a resonator is the Helmholtz resonator, which has the shape of a bottle. The resonant frequency is governed by the size of the opening, the length of the neck and the volume of air trapped in the chamber. Typically, perforated

materials only absorb the mid-frequency range unless special care is taken in designing the facing to be as acoustically transparent as possible. Slots usually have a similar acoustic response. Long narrow slots can be used to absorb low frequencies. For this reason, long narrow air distribution slots in rooms for acoustic music production should be viewed with suspicion since the slots may absorb valuable low-frequency energy. [14]

CHAPTER 5

Theoretical Basis of Sound Insulation

The sound insulation or sound transmission loss of a wall is that property which enables it to resist the passage of noise or sound from one side to the other. This should not be confused with sound absorption which is that property of a material which permits sound waves to be absorbed, thus reducing the noise level within a given space and eliminating echoes or reverberations.

Measurement of Sound

The sound insulation of a building assembly is expressed as a reduction factor in decibels (dB). The decibel is approximately the smallest change in energy the human ear can detect, and the decibel scale is used for measuring ratios of sound intensities. The reference sound intensity used to measure absolute noise levels is that corresponding to the faintest sound a human ear can hear (0 dB). However, a difference of 3 or less dB is not especially significant, because the human ear cannot detect a change in sounds of less than 3 dB.

Sound Transmission Loss

It is desirable to have a single number rating as a means for describing the performance of building elements when exposed to an "average" noise. In the past it was customary to use the numerical average of the transmission loss values at nine frequencies. This rating, termed the *nine-frequency average transmission loss,* is often quite inaccurate in comparing an assembly of materials having widely differing TL-frequency characteristics. One single number rating method which has been recently proposed is the *sound transmission class* (STC). This rating is based on the requirements that the value of transmission loss at any of the eleven measuring frequencies does not fall below a specified TL-frequency contour. The shape of this contour is drawn to represent

The more common types of noise, and generally covers the requirements for speech privacy.

CHAPTER 6

Measurements in the Laboratory

I decided to use materials that are commonly seen. Then I will compare sound insulation effectiveness on the different materials under different frequencies in term of Sound Reduction Index(R) and Transmitted coefficient (T).

Equipment Used in Measurements

Decibel Meter – SPL Meter Ipad Application: Using a decibel meter we can measure the sound level in (db) performance for each material in the experiment.

Figure 11 – Decibel Meter

sound level (L)

$$L = 10 \log_{10} [\, I/I_0 \,] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1$$

sound reduction index (R):

$$R = 10 \log_{10} [\, 1 / T \,] \text{ (dB)} \ldots\ldots\ldots\ldots (2)$$

T: *Transmitted sound energy / Incident sound*

Figure 12 –Sound Reduction Index

Expandable Polystyrene

Stainless Steel

Paper

Wood

Figure 13 –Sound Reduction Materials

Sound Proofing

Soundproofing is any means of reducing the sound pressure with respect to a specified sound source and receptor. There are several basic approaches to reducing sound: increasing the distance between source and receiver, using noise barriers to reflect or absorb the energy of the sound waves, using damping structures such as sound baffles, or using active anti noise sound generators.

I will be using sound barriers to absorb the energy of the sound waves. The energy density of sound waves decreases as they spread out, so that increasing the distance between the receiver and source results in a progressively lesser intensity of sound at the receiver. In a normal three dimensional setting, with a point source and point receptor, the intensity of sound waves will be attenuated according to the inverse square of the distance from the source. I will use the same distance for each test.

Damping

Damping means to reduce resonance in the room, by absorption or redirection (reflection or diffusion). Absorption will reduce the overall sound level, whereas redirection makes unwanted sound harmless or even beneficial by reducing coherence. Damping can reduce the acoustic resonance in the air, or mechanical resonance in the structure of the room itself or things in the room.

Absorption

Absorbing sound spontaneously converts part of the sound energy to a very small amount of heat in the intervening object (the absorbing material), rather than sound being transmitted or reflected. There are several ways in which a material can absorb sound. The choice of sound absorbing material will be determined by the frequency distribution of noise to be absorbed and the acoustic absorption profile required.

Porous Absorbers

Porous absorbers, typically open cell rubber foams or melamine sponges, absorb noise by friction within the cell structure. Porous open cell foams are highly effective noise absorbers across a broad range of medium-high frequencies. Performance is less impressive at low frequencies.

The exact absorption profile of a porous open cell foam will be determined by a number of factors including the following:

- Cell size
- Tortuosity
- Porosity
- Material thickness
- Material density

Apparatus

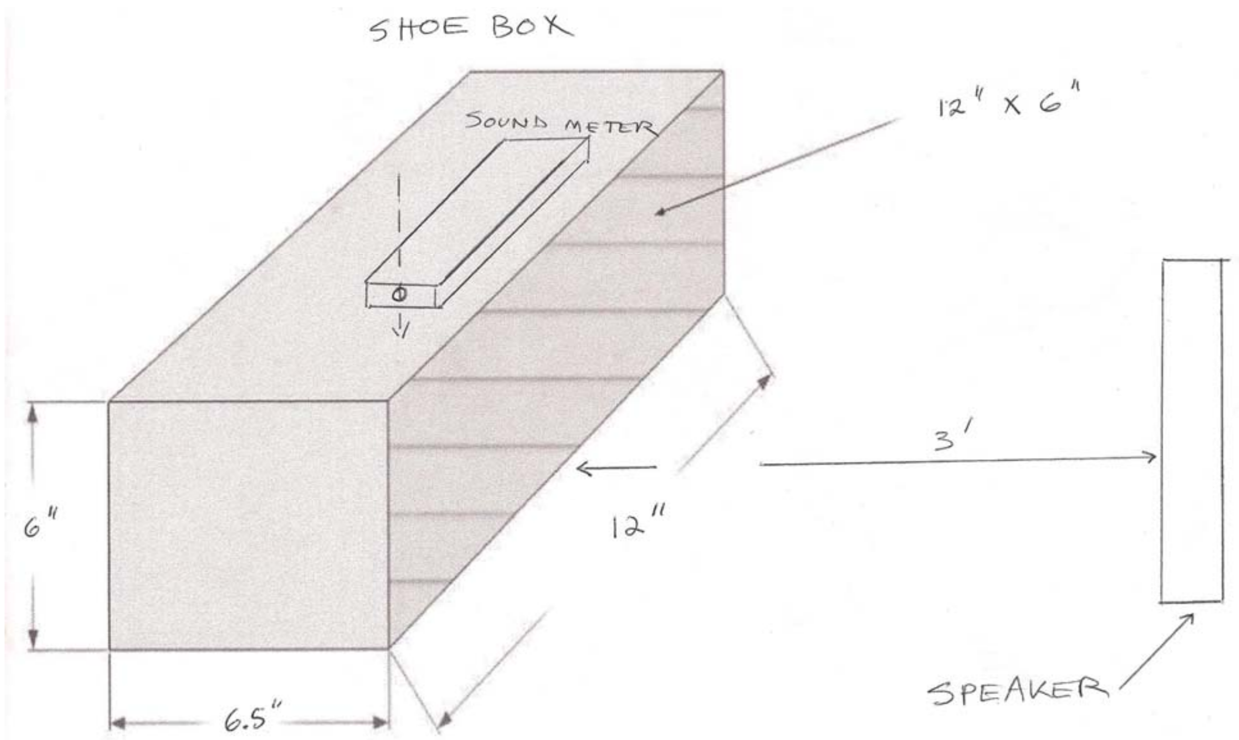

Figure 14 –Apparatus

Frequencies Chosen

F1 – 125 Hz

F2 – 250 Hz

F3 – 500 Hz

F4 - 1 kHz

F5 – 2 kHz

Materials Thickness Used

EPS FOAM	.7”	THICKNESS
STEEL BOARD	.08”	THICKNESS
WOODEN BOARD	.47”	THICKNESS
PAPER (50 SHEETS)	.20”	THICKNESS
PAPER (100 SHEETS)	.20”	THICKNESS

Experimental Procedure

1. Turn on speaker and generate 125Hz
2. Measure sound level using SPL meter and record the readings
3. Using EPS Foam in front of box so that it covers the opened part of the box
4. Measure sound level and take 3 readings.
5. Repeat steps 1 thru 4 for the other materials in the experiment
6. calculate the average sound level (Laverage = ((L1+L2+L3)/3), Sound reduction index ® and transmitted coefficient (T) for different material under different frequency.
7. Show relation between R/T and different frequencies for different materials

Experimental Assumptions

1. The unique sound source for the experiment is the frequency generator
2. Backround noise is kept constant
3. The reflection and refraction effects of sound are negligible

CHAPTER 7

Experimental and Theoretical Results

Materials	F1	F2	F3	F4	F5	Sound Level
	125Hz	250Hz	500Hz	1kHz	2kHz	
EPS Foam	60	71	70	75	77	L(average) (dBb)
7” Thick	3.2	1.4	1.5	.50	5.2	R(db)
	.5	.7	.7	.9	.3	T
Steel Board	62	59	53	53	55	L(average) (dBb)
.08” Thick	5.5	9.0	5.0	15.0	19.2	R(db)
	.3	.2	.4	.02	.01	T
Wooden Board	69	68	57	56	51	L(average) (dBb)
.47” Thick	3.5	4.0	5.0	10.9	22.	R(db)
	.45	.4	4.6	10.9	22.0	T
A4 Paper	57	75	75	69	72	L(average) (dBb)
.20” Thick	1.5	1.0	1.0	2.0	2.2	R(db)
	.7	.8	.8	.6	.6	T
A4 Paper	54	65	75	64	69	L(average) (dBb)
.40” Thick	1.8	2.6	1.7	6.5	5.5	R(db)
	.7	.5	.7	.3	.3	T

Table 1 –Experimental Results

CHAPTER 8

Conclusions

1. The greater the R, the greater the sound reduction level.
2. The smaller the T, the greater the sound reduction level.
3. The most effective sound insulation material is the steel board.
4. the least effective sound insulation materials are the EPS foam and A4 Paper(50sheets).

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