An Industrial Audiological Approach to Design and Construction of Enclosures for Control of Noise

1975

Dale G. Smart

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AN INDUSTRIAL AUDIOLOGICAL APPROACH TO
DESIGN AND CONSTRUCTION OF ENCLOSURES
FOR CONTROL OF NOISE

BY

DALE G. SMART
B.S., Michigan Technological University, 1953
B.S., Florida Southern College, 1973

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Arts
in the Graduate Studies Program of the
College of Social Sciences Florida Technological University

Orlando, Florida
1975
I wish to express my appreciation to those individuals without whose help this study would not have been completed.

To my committee Chairman, and friend, Dr. Tom Mullin, whose attention to detail, encouragement and professionalism, has made my experience at FTU enriching and pleasurable.

My gratitude is also extended to the other members of my committee, Dr. E. B. Wycoff and Dr. R. W. Buchanan for their suggestions and assistance.

I want to recognize the invaluable assistance rendered by Employers Insurance of Wausau, Wisconsin, my employer, and specific thanks to Mr. Mark Veckman of Employers Insurance of Wausau for his help and use of his diagram of an enclosure for an Ultrasonic welding machine.

A thank you to Maggie Richardson for her help in organizing and typing the manuscript.

Finally, my deepest appreciation to my wife, Gertie, for her patience during some long hours when we wondered if this would ever be completed.
to my son, Jon,
whose frequent expressions of pride in his father
and his own academic achievements
kept me working this thesis
is affectionately dedicated
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Introduction and Rationale

The Problem of Noise

When sound has an undesirable effect and is unwanted, we call it noise (Maineri, 1972). Noise can be more than a mere nuisance and is taking its place alongside air and water pollution as a major and growing concern (Olishifski, 1968). Under certain conditions, noise can kill a fish, break a wine glass, burst a plate glass window, undermine the structural foundations of buildings, and damage parts of the human body (Stevens, et al., 1971). Civilization has created an environment where noise is becoming a serious economic and social problem. Relatively low noise levels may produce anxiety, nervousness and irritability - and these can lead to circumstances which can be instrumental in other types of injury, particularly in a work environment where hearing is vital to efficient operations (Hermann, 1969). Broadbent (1968) found that the effects of noise on work output depended greatly on the nature of the work performed. In jobs for which continual attention was needed, and which extended for long periods of time, the effect of noise seemed to be greater. A higher error rate as well as accidents, was indicated as more likely in such situations, rather than any noticeable reduction in the volume of work. Jet planes, motorcycles, trucks, outboard motors and cars are creating a cacophony of sound that beats on our ears at home, on the streets and at work. The
mechanization of our way of life has resulted in people being exposed to the highest and most dangerous noise levels in history (Maineri, 1972).

The most obvious damage from noise to man is deafness (Maas, 1970). Sudden and unexpected noises from different sources can not only rupture an ear drum, but can produce other physiological changes in the human body. Just as white corpuscles in the blood stream gather at a point of infection, so does our body react to noise; perspiration increases, blood pressure rises, muscles contract sharply and digestion ceases (Beranek, 1960).

Other reactions, such as eye blinking, crying, or drawing the legs up into a defensive position have been described by Miller and Polisar (1971). Maineri (1972) reports loud noise can cause such unpleasant sensations as vibrations of the eyeballs and head, loss of balance, and heating of the skin. The current craze of teenagers for loud music, with the apparent criteria being the louder the better, and the urge to get as close to a group of noise creating musicians as possible, can cause temporary hearing loss, and if repeated often enough, will result in permanent hearing impairment (Sataloff and Michael, 1973). Grove (1949) pointed out that "long, continued noise menaces health and destroys efficiency. It produces fatigue ...It encourages inattention and lack of concentration." He continued by pointing out that persons subjected to such irritants become "jumpy, jittery and irritable." Grove concluded that
neurastenia and psychastenia develop, which are not incomparable to battle fatigue. Lipscomb (1975) played "hard rock" music to guinea pigs with the same intensity (122 dBA) that he measured while recording it at a discotheque. The guinea pigs were exposed to a four hour daily dosage of the music over a three month period. Lipscomb reported that as many as 25 percent of the cochlear cells of the animals were destroyed by the noise. In studying children, Lipscomb (1975) indicated that among sixth graders, less than four percent had high frequency hearing impairment, but among twelfth graders, nearly 11 percent showed impairment and more than 30 percent of the freshmen studied in a state university had hearing loss which he concluded as evidence of hearing loss as a function of time of exposure to noise.

**Physics of Sound**

Maas (1967) describes airborne sound as rapid variations in atmospheric pressure. These pressure variations are set up by any vibrating body and are called sound waves. Their speed is approximately at 1,130 feet per second while traveling through the atmosphere. Sound waves are similar to those waves produced in a pond when a pebble is thrown into it. The waves move outward in concentric circles. The primary difference though is that sound waves move outward in all directions, while the waves on the water move only along the waters surface (Buntaine, 1945). To most,
Buntaine continues, sound would be thought of as anything we hear. To a physicist, however, it may be defined as a form of vibrational energy which may cause the human ear to react, and is usually transmitted to the ear through air (Buntaine, 1945).

Sound has two fundamental characteristics; frequency (perceived by the ear as pitch), or the number of sound waves per second, and intensity (related to loudness and sound pressure), determined by the amplitude of the sound wave (Walworth, 1967; Davis and Silverman, 1970). The human ear is responsive to frequencies ranging from approximately 20 to 20,000 cycles per second (Hertz). Sound can consist of a single frequency (puretone) such as is produced by an audiometer, or a combination of many frequencies as is found in industrial noises (Davis and Silverman, 1970).

In acoustics, frequencies are delineated in octaves, similar to that which is done for a piano keyboard (Miller and Thumann, 1974). Octave means the interval between any two sounds having a frequency ratio of two to one (Maas, 1967). The higher the frequency measured in Hertz (Hz), the higher one perceived its pitch (Welch and Welch, 1970).

Pressure variations in a sound wave are measured in terms of a unit called the microbar (Harris, 1957). A microbar is one-millionth of the normal atmospheric pressure. The range of sound pressures to which the ear is exposed is almost incalculable, Harris
continued. In order to express this wide range of pressure in numbers that could be handled more conveniently, a unit called the bel was selected. The bel can be defined as the logarithm of the ratio of two sound pressures (Harris, 1957). For practical reasons of calculations, one-tenth of a bel, the decibel (dB) is more commonly used.

The instrument used for measuring the intensity of noise is known as a sound level meter (Beranek, 1960; Rosell, 1974). This meter employs several scales of measurement, however, for our purposes the most commonly used, the "A" scale will be the only one considered. The "A" scale (dBA), which is defined as having a reference level of 0.0002 microbar, reacts in much the same way as the human ear responds to noise by attenuating the lower frequencies about 5 dB per octave from 1,000 Hz down to 250 Hz (Clayton, 1966).

Tobias (1972) elaborated on the actions of sound waves, by likening them not only to waves in the water, but also light beams. The sound waves travel in straight lines directly away from their source, and perpendicularly to the wavefronts. Like light, they will reflect from some things and be absorbed by others. Unlike light however, Tobias continues, some sound waves will flow around objects they strike and keep on going as though nothing was present. The size of an obstacle relative to the sound wavelength will determine whether sound will be reflected, absorbed or unaffected. Stevens, et al., (1971) explained that objects that are smaller
than the sound wavelength will not affect the sound waves a great deal. The wave will be refracted around it and continue on. If an object is larger than the waves, the sound will be reflected. Familiarity with these basics is necessary when efforts to abate or control noise is discussed.

**Noise and Hearing**

Many researchers (Kryter, 1950; Hardy, 1952; Harris, 1957 and Burns, 1973) report that exposure to noise of sufficient intensity and duration produce sensorineural hearing loss in man. Exposure to intense sudden noise may produce serious damage to the middle and inner ear. The ear drum can be ruptured and the bones of the middle ear, the ossicular chain, be disarticulated by the pressure wave created. The basilar membrane and organ of Corti can be dislocated by high pressure waves (Burns, 1973).

There are three basic types of hearing losses: (1) conductive, (2) sensorineural and (3) mixed (Davis and Silverman, 1970). A conductive loss is the hearing impairment due to interference with the acoustics transmission of sound to the sense organ, usually in the outer or middle ear (Welch, 1970). In conductive hearing losses the hearing threshold levels (the lowest level stimulus which elicits a response 50 percent of the time) measured by bone conduction are normal, whereas the air conduction hearing levels may be up to 60 dB poorer than the bone conduction scores (air-bone gap) (Davis and
One of the characteristics of a conductive hearing loss is the fact that it is medically or surgically treatable; whereas, the sensorineural type is rarely influenced by medical or surgical intervention (Shambaugh, 1967).

A sensorineural hearing loss is the hearing impairment due to abnormality of the cochlea, the auditory nerve, the brain or any combination of these and the air-bone gaps are smaller or absent in this type of hearing impairment (Hermann, 1969).

A mixed loss is a combination of the conductive and sensorineural type wherein the bone conduction thresholds are below normal but not as poor as the air conduction hearing levels (Kryter, 1963).

Hermann (1969) states that puretone audiometry is the most widely used in obtaining information about hearing abilities. He explains that due to the variation in human hearing acuity, which occurs with changes in frequency or pitch, audiometric zero reference levels are different for each puretone employed. In 1964, the International Standards Organization (ISO - 1964), and later the American National Standards Institute (ANSI - 1969) established values for puretone audiometric measurements (Hermann, 1969).

It is generally acknowledged (Kryter, 1950; Hermann, 1969; Maineri, 1972) that exposure to 85 dBA does not produce significant hearing losses if limited to less than 40 hours per week, even if such exposure has continued over many years. On the other hand, Glorig and Davis (1961) demonstrated that 1,948 persons exposed throughout
their work careers to no more than 79 dBA had measurable shifts in hearing acuity and that these shifts were probably due to noise exposure.

There seems to be a general agreement (Welch and Welch, 1970; Maineri, 1972; Olishifski, 1975) that an inability to hear and understand everyday speech constitutes the best measure of the communicative handicap inflicted by noise exposure. Fox (1970) states that a young adult with normal hearing can perceive frequencies of range 20 to 20,000 Hz, though he requires only hearing from 500 to 2000 Hz in order to understand most speech. Normal hearing relative to intensity is from 0 to 130 dB, (ANSI - 1969) with conversational speech approximately 40 to 50 dB, (ANSI - 1969). Persons demonstrating poorer than 25 dB hearing levels in the speech range (500 - 2000 Hz) begin to have difficulty in normal comprehension of speech (Tobias, 1972). It was from this data that noise exposure criteria have been proposed and adopted to prevent hearing impairment (Occupational Safety and Health Act - 1970).

Davis and Silverman (1970) report that when hearing impairment is calculated by averaging the hearing threshold levels at 500, 1000 and 2000 Hz, the degree of risk associated with high noise levels can be estimated. Hardy (1952), Rosenblith and Stevens (1953), and Kylin (1960), report data showing that continuous exposure to noise levels exceeding 85 dBA will increase the probability of hearing loss.
Legal Considerations

The problem of noise in industry is currently receiving much attention because, in recent years, noise has become more intense and widespread due to the increase in mechanization of industry and a growing concern for the safety, efficiency and morale of personnel (Tyzzer, 1953). In addition, Congress passed, and the President of the United States signed into law, the Occupational Safety and Health Act (OSHA), in December, 1970. This law, and its predecessor, the Walsh-Healey Public Contracts Act (1969), created new regulations and standards of noise control for management and labor. These new reforms have created enormous problems of how industry is to comply to such regulations and how the Occupational Safety and Health Administration will enforce them. Such questions have consumed many man-hours and considerable expenditures of funds for both government and industry. Two studies recently completed for hearings on the noise standards of OSHA estimated the costs for compliance to the standard which is being considered - 5 dBA lower than present - at from $12 billion to $30 billion (Mossberg, 1975). On the other hand, claims for workman's compensation for noise induced hearing losses could potentially cost industry many times this amount (Symons, 1953; Olishifski, 1975).

Man has always been exposed to some type of noise, but it has only been in the last 20 to 25 years that much attention has been given to the assessment of high noise levels and their effects on
man's ability to hear (Olishifski, 1968). The recent attention has undoubtedly resulted from the development of increased noise levels and the interest and welfare of workers (Fisher, 1975).

Before the advent of Workmen's Compensation Laws, and employers' common law defense was based on (1) employee's assumption of risk, (2) negligence of fellow employees, and (3) employer's contributory negligence. In addition, the employee had to prove the negligence of the employer beyond any doubt (Mehr and Cammack, 1966). It was true that the employer was supposed to provide for the safety of his workers, but also in consideration at that time, was the fact that the employee was theoretically free to refuse employment if he felt the work was hazardous. This law, considered the common law, was first recognized in 1841, as applying to the United States in a case Murray vs. the South Carolina Railroad Company (Larson, 1955). Larson further reported that in 1869, the Combs vs. New Bedford Cordage Co. case established the liability of the employer when he failed to warn his employees of unusual dangers relative to their work. In the early days of the development of industrial America, it was common for injured workers to be thrown on the charity of their neighbours or friends in order to survive. From the employers' standpoint, they suffered unfavorable publicity and unreasonably high judgements when they were awarded. Generally, however, there were few compensations to injured employees (Mehr and Cammack, 1966).

Workmen's compensation laws were probably first inspired by J. G. Brooks in 1893, when he outlined the system developed in Germany
under Bismarck which held the premise that the cost of compensating occupational injury cases should be made a part of the cost of producing a product (Larson, 1955). A number of states were then inspired to develop their own compensation laws. Massachusetts organized the first study commission in 1904, followed by Illinois in 1907, Connecticut in 1908, New York in 1909 and several others in 1910. The oldest Workmen's Compensation Act in the United States is the 1908 Federal Employees Compensation Act covering civilians employed by the Federal Government. The oldest state Workmen's Compensation Law is believed to be that passed in New York in 1910 (Mehr and Cammack, 1966).

From a noise and loss of hearing standpoint, perhaps the major incident that stimulated interest occurred in the 1950's and involved litigation concerning the Slowinski case in New York State (Walworth, 1969). The New York Workmen's Compensation Board ruled that the schedule for traumatic hearing loss applied to both accidental injuries and occupational diseases, and that Slowinski was entitled to a schedule award for partial loss of hearing even though he suffered no loss of wages as a result. Thirty-nine states and the District of Columbia presently permit payment of Workmen's Compensation for partial loss of hearing due to noise exposure (Fox, 1969).

Paragraph 1910.95 of the Federal Occupational Safety and Health Act (Appendix A) deals with the permissable noise exposures under occupational conditions. This act adopts the standards originally
established in the Walsh-Healey Act, Section 50-204.10. The standard sets the exposure time allowed for eight hours at no more than 90 dBA. The maximum allowable noise level is 115 decibels (115 dBA), and then for only 15 minutes total exposure per eight hours. OSHA states specifically that occupational noise exposures which exceeds the limits specified shall be controlled by any feasible engineering methods or administrative controls. Personal protective equipment shall be permitted during the period required for the institution of engineering or administrative controls or where it can be demonstrated that engineering control is not feasible. Research is currently underway in many firms to control the source of noise. Undoubtedly, as more knowledge and experience in acoustical engineering is acquired, new methods of abating noise to within allowable limits will be discovered.

Acoustical Engineering

A highly practical and ultimately economical approach to a noise problem is to first obtain sound pressure levels and to then analyze at what octave bands these noises occur. The data should be obtained with the particular piece of offending machinery "on", "off", and in various types of operating modes including measurements made while other machines nearby are also in operation, so that the total noise picture might be considered (Miller and Thumann, 1974).

Common to all noise problems is the source of noise radiation,
the path of propagation, and the receiver of the noise (Miller and Thumann, 1974). The normal procedure is to determine whether the source or the path is the cause of the problem. If the source cannot be treated, then the only method remaining to resolve the noise problem, is to work on the path. The receiver, or exposed individual can be protected by utilizing either administrative controls, (i.e. moving him to another area after a period, etc.) or by providing individual personal protection (i.e. plugs, or muffs etc.) (Cheever, 1967). It should be borne in mind, however, that under federal law, the use of personal protection devices are considered an interim measure only, and then only when other treatment is not feasible (Fisher, 1975).

Callaway (1953), Cheever (1967), and more recently Crocker (1974) and Miller and Thumann (1974), have written and tested engineering methods. Handley (1970) followed up the Walsh-Healey Act with some practical advice on engineering controls by combining engineering and administrative controls to maintain a total days dosage below permissable levels.

One of the more easily instituted controls prescribed by Handley (1970) involves nothing more than proper lubrication of equipment, or sharpening cutting edges such as in the case of table saws for example. Good maintenance practices are most practical and in many cases can reduce the exposure sufficiently to comply with law and protect employees from the noise source. Substitution of equipment or procedures, such as plastic gravity chutes for ones
of metal, substituting fiberglass ductwork for metal, belt drives for gears, welding instead of riveting, pressing or rolling instead of forging, are also effective noise reduction practices (Handley, 1970).

Probably no noise puts greater strain on nervous energy than compressed air discharge (Harris, 1957). The usual cause for such high noise levels is that air actuated tools, such as blow-off nozzles, are often operated at pressures much greater than is necessary (Harris, 1957). He points out that such high pressures, (up to 115 pounds per square inch - 115 psi) as is often used, is not necessary for efficient operation of such tools, and that often 15 psi is adequate.

When the simplistic solutions are exhausted, such as maintenance, substitution, and modification techniques, the use of acoustical barriers or enclosures should be considered (Clayton, 1966). Such engineering controls must be designed to either enclose the source of the noise, improve the general acoustic environment, or enclose the worker (Tyzzer, 1953).

Enclosures

Enclosures reduce the transmission of noise by using acoustical material to absorb sound waves and reduce reverberations to areas occupied by workers. The computation of source acoustical power levels and sound pressure levels have been generally accepted method
in enclosure design (Tyzzer, 1953; Callaway, 1953; Beranek, 1960). These computations require more experience and knowledge of physics of sound than is generally found in most industrial operations. Thus, oftentimes, enclosures have been developed through mandates from managers or others without having the knowledge of engineering, noise abatement procedures, or law requirements, with the result that the finished product is either inadequate for the job or else far exceed required standards and allotted funding (Fader, 1966; Miller, 1971). Noise reduction is a complex subject and in many cases it is preferable to employ the services of a person with the qualifications to analyze the noise problems, compute the acoustical power levels, and sound pressure levels, and to recommend the type of enclosure design. These professionals are few in number and oftentimes their services are beyond the fiscal ability of some firms.

It is believed that through the intelligent use of sound level meters and the application of basic principles of sound absorption principles, that a method can be devised to greatly reduce the amount of time which has been expended in the past in developing enclosures to reduce noise levels. A simpler method would bring information regarding enclosure of noise sources within the reach of plant personnel who have received only limited education in the realms of noise abatement.
Statement of the Problem

Noise in industry is currently receiving much attention because, in recent years, noise has become more intense and widespread due to the increase in mechanization of industry, growing concern for the safety, efficiency, and morale of personnel, and the passage of legislation which has established specific limits of noise exposure in industrial operations. Management is required to take action to reduce industrial noise either by engineering or administrative means wherever possible. Such means might include modification of machinery, use of specifically designed enclosures, isolation of machine or workers, reduction of exposure times, etc.

Enclosures are designed to absorb noise and thus protect machine operators. Such enclosures have oftentimes developed through management mandates, and become the problem of personnel not equipped with the knowledge or talent to build them. This has led to the construction of costly enclosures which sometimes fail to meet the legal requirements.

The purpose of this study will be to develop a simplified system which can be used by those not sophisticated in the area of acoustics or audiology, in the construction of acoustical enclosures. Such a system will be devised through field studies, research of
available data on the noise absorption qualities of various materials, and considerations of noise effects on man.
Methodology

Design

Letters (Appendix B) were sent to representative manufacturers of acoustic building materials as listed in the Directory of Noise Control Products as published by the National Safety News, in order to determine sound absorbing qualities of their products. Letters were also sent to federal and state agencies involved in noise abatement programs, such as the United States Bureau of Standards, involved in noise abatement programs requesting available data on enclosure specifications (Appendix C).

Sound level studies were performed on various enclosures presently in use in various Central Florida firms having noise problems. The dBA levels obtained were compared with noise levels existing prior to erection of the enclosures.

Instrumentation

A sound level meter (Bruel and Kjaer, Model 2205), utilizing the "A" scale at slow response as required by OSHA (1970) standards, was employed for all measurements of noise. The sound level meter was calibrated prior to and following all measurements following procedures established by the American National Standards Institute.
Procedure

Responses from both mailings (Appendices B and C) were tabulated and recorded so that analysis of attenuation, costs and ease of utilization might be assessed.

Calibration of the sound level meter (SLM) was performed at the onset of all testing. The SLM was set for the "A" scale at "slow" response. All readings were made with the meter in the examiners left hand at the ear level of the worker with the microphone facing the noise source. Noise levels (dBA) were recorded on standard noise level survey report forms (Appendix D).

Upon completion of the noise survey, the SLM was checked for calibration.

Data Analysis

Information returned from mailings to acoustical building materials manufacturers and governmental agencies was analyzed in regard to attenuation (noise reduction) qualities, cost, and difficulty of utilization.

Noise level measurements obtained in the plants sampled was compared with readings obtained before such enclosures were constructed.
Results

Materials Survey

Table 1 illustrates the attenuation qualities, costs, weight, availability and serviceability of acoustical materials, obtained from mailings to manufacturers of such materials. Additional data gathered from analysis of responses from governmental agencies has also been included in this table.

Inspection of Table 1 reveals that most of the materials are readily available with the exception of sheet lead of either 1/8 inch or 1/16 inch in thickness, and 3/4 inch solid oak panels.

Serviceability (handling ease and durability) is also indicated to be good with most materials, however, as can be seen in Table 1 gypsum wallboard (one inch thick) and plaster (six inches thick) are listed as only fair in this regard.

Weight per square foot ranged from a low of ½ pound per square foot for one inch thick fiberglass (six pounds per cubic foot density), to a high of 58 pounds per square foot for four inch thick concrete slab. Brick, four inches thick is also in the heavier category with a weight of 44 pounds per square foot. The mean weight of the twenty materials described is ten pounds per square foot with a medium weight of four pounds per square foot.
### TABLE I

Sound Transmission Loss of General Building Materials and Structures Obtained from Responses Received from Manufacturing Companies and Governmental Agencies

<table>
<thead>
<tr>
<th>Item</th>
<th>Materials or Structure</th>
<th>Weight lbs/ft²</th>
<th>Loss in dB</th>
<th>Availability</th>
<th>Serviceability</th>
<th>Cost/sq.ft.</th>
</tr>
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<tr>
<td>1</td>
<td>Door 3/16&quot;, wood panels</td>
<td>1</td>
<td>15</td>
<td>Good</td>
<td>Good</td>
<td>$1.25</td>
</tr>
<tr>
<td>2</td>
<td>Glass, 1/8&quot;, dbl str</td>
<td>1.7</td>
<td>26</td>
<td>Good</td>
<td>Good</td>
<td>.60</td>
</tr>
<tr>
<td>3</td>
<td>Glass, 1/4&quot;, plate</td>
<td>3</td>
<td>30</td>
<td>Good</td>
<td>Good</td>
<td>1.10</td>
</tr>
<tr>
<td>4</td>
<td>Plywood, 1/4&quot;, on 1&quot;x3&quot;studs both sides</td>
<td>3</td>
<td>25</td>
<td>Good</td>
<td>Good</td>
<td>.50</td>
</tr>
<tr>
<td>5</td>
<td>Gypsum, wall-board, 1&quot;</td>
<td>4.5</td>
<td>30</td>
<td>Good</td>
<td>Fair</td>
<td>.18</td>
</tr>
<tr>
<td>6</td>
<td>Door, 1 3/4&quot;, Solid Oak</td>
<td>7</td>
<td>20</td>
<td>Fair</td>
<td>Good</td>
<td>4.00</td>
</tr>
<tr>
<td>7</td>
<td>Glass, 1/2&quot;</td>
<td>6.5</td>
<td>35</td>
<td>Good</td>
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<td>Fair</td>
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<td>9</td>
<td>Door, airtight 2½&quot; wood</td>
<td>14</td>
<td>30</td>
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<td>48</td>
<td>Good</td>
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<td>.75</td>
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<tr>
<td>12</td>
<td>Conc. Slab, 4&quot;</td>
<td>58</td>
<td>48</td>
<td>Good</td>
<td>Good</td>
<td>*</td>
</tr>
<tr>
<td>Item</td>
<td>Materials or Structure</td>
<td>Weight lbs/ft²</td>
<td>Loss in dB</td>
<td>Availability</td>
<td>Serviceability</td>
<td>Cost/sq.ft.</td>
</tr>
<tr>
<td>------</td>
<td>------------------------</td>
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<td>--------------</td>
<td>----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>13</td>
<td>Lead, single sheet 1/8&quot; thick</td>
<td>8</td>
<td>35</td>
<td>Fair</td>
<td>Good</td>
<td>4.00</td>
</tr>
<tr>
<td>14</td>
<td>Lead, single sheet 1/16&quot; thick</td>
<td>4</td>
<td>32</td>
<td>Fair</td>
<td>Good</td>
<td>2.00</td>
</tr>
<tr>
<td>15</td>
<td>Fiberglas, 6lb ft³ density, 1&quot; thick</td>
<td>0.5</td>
<td>4.5</td>
<td>Good</td>
<td>Good</td>
<td>0.06</td>
</tr>
<tr>
<td>16</td>
<td>Fiberglas, 6lb ft³ density, 2&quot; thick</td>
<td>1</td>
<td>7.5</td>
<td>Good</td>
<td>Good</td>
<td>0.07</td>
</tr>
<tr>
<td>17</td>
<td>Fiberglas, 6lb ft³ density, 3&quot; thick</td>
<td>1.5</td>
<td>10</td>
<td>Good</td>
<td>Good</td>
<td>0.08</td>
</tr>
<tr>
<td>18</td>
<td>Fiberglas, 6lb ft³ density, 4&quot; thick</td>
<td>2</td>
<td>12.5</td>
<td>Good</td>
<td>Good</td>
<td>0.09</td>
</tr>
<tr>
<td>19</td>
<td>2&quot;x4&quot; studs, 1/2&quot; insul.bd. both sides (16&quot; ctrs)</td>
<td>4</td>
<td>34</td>
<td>Good</td>
<td>Good</td>
<td>0.10</td>
</tr>
<tr>
<td>20</td>
<td>2&quot;x4&quot; studs, 3/4&quot; insul.bd. both sides (16&quot; ctrs)</td>
<td>4</td>
<td>32</td>
<td>Good</td>
<td>Good</td>
<td>0.12</td>
</tr>
</tbody>
</table>

* Primary Cost is labor, not material.
Attenuation qualities ranged from a minimum of 4.5 dB for one inch thick fiberglas (six pounds per cubic foot density) to a maximum of 48 dB for both four inch thick brick and four inch thick concrete. The mean attenuation value is 27 dB with a median value of 30 dB.

Costs of purchase of the described materials varied from a low of $.06 per square foot for one inch thick fiberglass (six pounds per cubic foot density) to a high of $8.00 per square foot for a 2½ inch thick airtight wood door. The mean cost was $1.52 with a median expense of $.92 per square foot.

Field Studies

Table II represents typical examples of noise surveys in industrial environments visited and the effects sound enclosures have made on noise reduction.

Table II illustrates noise reduction through use of enclosures constructed from representative materials. Noise levels are reported for both before and after construction of these enclosures. As can be seen, plexiglas seems to be most effective as an attenuating material, reducing the noise levels by 24 dB in the examples given.
TABLE II

Comparison Noise Levels Before and After Enclosure Construction

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Noise Level w/o Enclosure</th>
<th>Noise Level w/Enclosure</th>
<th>* Materials Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neckring Press</td>
<td>99</td>
<td>89</td>
<td>Plywood w/lead lining</td>
</tr>
<tr>
<td>Endcap Press 1</td>
<td>103</td>
<td>86</td>
<td>&quot;</td>
</tr>
<tr>
<td>Endcap Press 2</td>
<td>103</td>
<td>90</td>
<td>&quot;</td>
</tr>
<tr>
<td>Shellringer Press</td>
<td>99</td>
<td>90</td>
<td>&quot;</td>
</tr>
<tr>
<td>Ultrasonic Welder</td>
<td>112</td>
<td>88</td>
<td>Plexiglas</td>
</tr>
<tr>
<td>Radial Arm Saw</td>
<td>99</td>
<td>89</td>
<td>Plywood with fiberglas insul.</td>
</tr>
<tr>
<td>Paper Mill Machine</td>
<td>103</td>
<td>82</td>
<td>Alum. outer panel w/plywood and fiberglas insul. interior</td>
</tr>
<tr>
<td>Tumbler</td>
<td>104</td>
<td>82</td>
<td>&quot;Masonite&quot;, wood, fiberglas insul.</td>
</tr>
</tbody>
</table>

* Typical illustrations of enclosures and their effectiveness are shown in Appendix "F".
The field studies performed resulted in reinforcing the formulation of the guidelines that are performed in the construction of sound enclosures. These guidelines, if followed, will provide the unsophisticated worker with the pre and post construction acoustical data that will produce the most beneficial results. These guidelines are as follows:

Step 1 - determine noise levels being generated by offending equipment at operator through use of a certified sound level meter.

Step 2 - refer to OSHA standards which describe permissible levels of noise and determine if levels measured in Step 1 exceed standards for the period of worker exposure.

Step 3 - determine attenuation required to comply with federal standards by subtracting results of Step 2 from results of Step 1.

Step 4 - refer to Table 1 to select materials to be used based on the attenuation qualities indicated.

Step 5 - construct enclosure, using proper building design and techniques.

Step 6 - remeasure noise levels and compare with those recorded in Step 1 to determine actual attenuation values.
Prior to 1969, there were few, if any, specific standards regarding noise exposure to workers in industry. The recent passage of laws in this area have pointed up the necessity for providing an efficient means for measuring noise and how this pollutant can be reduced, often by personnel not especially knowledgeable in this discipline.

Oftentimes, when consultants in noise are called in, the process used for noise reduction is so technical that implementation of controls are too complicated for those who will have the "in-plant" responsibility and/or too prohibitive in cost for outside contractors.

Noise abatement is necessary due to the damage it may cause to humans. Therefore, readings at various points in the area where the equipment is located are only of value if they determine how much and whether workers are exposed to excessive noise. Where no others are exposed, the additional readings taken serve information purposes only and are of little pertinence to the general problem. Procedures established have required a minimum of six measurements at various degrees of different frequencies in a plane in line with the noise source, which necessitates the use of the Octave Band Analyzer (OBA). Following the gathering of such source
measurements, steps are then taken to predict the operators' exposure through determination of source acoustical power levels (PWL) which in turn may be used to calculate the Sound Pressure Level (SPL) at any other point of interest. The method utilizing the OBA is thorough and when properly and accurately carried through provides information enabling engineers or technicians to develop and design adequate combative measures.

As enforcement activity increased in regard to noise and the exposure of workers in an industrial atmosphere, the need for noise surveys and the services of technically qualified personnel increased also. Due to the limited availability of these services however, and the large number of situations needing attention, many operations have continued to be in violation, exposing employees to the harmful effects of noise.

To aid in the implementation of control procedures in noise producing environments, a simpler means of obtaining the pertinent information was believed necessary.

This procedure was developed and described in Results. It has been shown to be effective and feasible through field studies conducted. Utilization of information provided enabled an orderly process to be followed.

The method described provides information on the offending noise source in dBA, the established standard unit of measure, establishes what the federal standard is that must be met, and
provides a readily available source of information for determining what can be used to abate the noise level - and by approximately how much - and further gives an idea of the costs involved in constructing enclosures.

Selection of acoustical materials should, in addition to absorption properties, take into account fire resistance, cost, esthetic qualities, light reflection, susceptibility to damage, and ease of installation and maintenance. It will be noted that six categories were decided upon in assembling Table 1, covering most of these areas - (a) material (descriptive), (b) weight (lbs per square foot), (c) attenuation, (d) availability (judgemental - good, fair, poor), (e) serviceability, (f) cost (per square foot).

No attempt was made to determine variations in cost by area or supplier. It should be understood that such variations will exist. The judgement regarding availability was the result of local contacts and knowledge, advertisements, and telephone inquiry.

With this information and a certain amount of skill in carpentry or metal working, structures can be constructed that will not only comply with the federally imposed standards, but more importantly, will enable an operation with a noise environment that may be harmful, to take rapid and effective action to protect the most important industrial resource - its people.

Field Studies

Table II was developed as examples of the results of field
studies involving noise generating equipment, before enclosures were provided and afterwards. These serve as examples of the effectiveness and adequacy of the method developed.

No attempt has been made to design enclosures or barriers since designing involves familiarity with professional engineering disciplines, and such qualifications are not in the possession of this researcher. Certain information can be provided as general guidelines concerning barrier construction. Sound barriers utilize a material capable of retarding air-borne sound transmission. They are air-impervious materials, and they include such as masonry, asphalt-treated gypsum board, hardboard or plywood, plastic sheeting, lead coated vinyl sheeting, and metal sheeting or heavy foil sheeting.

With sound barriers of the air-impervious type, the incident sound waves set the sheet into vibration, and the sheet generates new sound waves of reduced intensity on the other side. The effectiveness of a barrier decreases directly with its weight per square foot. The heavier the material, the more difficult it becomes for the incident sound wave to produce any vibration of the wall. It is the vibration of the wall that causes sound to be radiated into the adjoining space.

A partition that combines the advantages of an absorbing material to reduce reverberation and a heavy, impervious panel to reduce the transmission of sound can obtain the optimum sound isolation possible with single-wall construction.

Commercially available are complete units, enclosures or
barriers, and these can be economically and feasibly utilized in most instances. However, many firms will prefer to construct their own, mainly due to unique situations encountered, the press of time, or the ready availability of material and personnel. The information in this paper is mainly directed to those who wish to construct their own. Whatever method is adopted in constructing enclosures, it is mandatory that one primary fact be kept in mind - there must be no leaks, no matter how small. In noise control, enclosure means that all cracks and openings are sealed so that the resulting structure is completely air tight.

Implications for Further Study

Studies regarding costs of completed enclosures utilizing expense of materials provided (Table I) would also be of value to management. Research regarding design and construction of enclosures could be performed by those with engineering background. Research on the psychological effects of certain materials used (i.e. eye appeal, texture, transparency etc.) in construction of sound enclosures would seem to be of considerable importance to the overall efficiency and general comfort of the worker exposed to industrial noise. Further research may provide information on new materials not included in Table I which will be superior to those studied.
Summary

Observations in the field and a review of literature showed that the determination of noise levels from offending machines or equipment was an extensive, and involved process requiring considerable expertise in equipment and the physics of sound. Realizing that workers are being exposed in industry to daily doses of noise which could be causing severe and permanent damage to hearing, and that the controlling of this noise is dependent on a process which is not readily available in all instances, it was decided the formulation of a procedure easier to implement and understand should be undertaken.

Information was gathered on equipment available for determining noise levels, deciding upon the sound level meter as the most practical for the cost involved; materials and cost for absorbing noise at the source; and the requirements of the federal law.

These enabled the development of a method for determining what the problem is, and how serious, and construction of an enclosure to reduce it, using information on the attenuation properties of materials.

It would seem to be a more convenient method of complying with standards, as well as a more rapid way of reducing the possible harmful effects of noise exposure to workers in industry.
APPENDIX A

1910.95 Occupational Noise Exposure

(a) Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table G-16 when measured on the A scale of a standard sound level meter at slow response.

(b) (1) When employees are subjected to sound exceeding those listed in Table G-16, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of Table G-16, personal protective equipment shall be provided and used to reduce sound levels within the levels of the table.

(2) If the variations in noise level involve maxima at intervals of one second or less, it is to be considered continuous.

(3) In all cases where the sound levels exceed the values shown herein, a continuing, effective hearing conservation program shall be administered.
Table G-16 Permissible Noise Exposures

<table>
<thead>
<tr>
<th>Duration per day, hours</th>
<th>Sound Level dB(A slow response)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>92</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
</tr>
<tr>
<td>3</td>
<td>97</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>1 1/2</td>
<td>102</td>
</tr>
<tr>
<td>1</td>
<td>105</td>
</tr>
<tr>
<td>1/2</td>
<td>110</td>
</tr>
<tr>
<td>1/4 or less</td>
<td>115</td>
</tr>
</tbody>
</table>

1 When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: \( \frac{C_1}{T_1} + \frac{C_2}{T_2} \) \( C_n/T_n \) exceeds unity, then, the mixed exposure should be considered to exceed the limit value. \( C_n \) indicates the total time of exposure at a specified noise level, and \( T_n \) indicates the total time of exposure permitted at that level.

Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.
Sample of letter to manufacturers of sound absorbing materials:

Sirs:

I am currently engaged in developing information on the attenuation properties of various materials for use in constructing enclosures to reduce machinery noise. This information is needed to aid in formulation of a method which can be used by individuals who have the responsibility for the development, design and construction of such enclosures. This method is being developed as part of a research project in the Department of Communication at Florida Technological University, Orlando, Florida. Although no company's name will be reported in this research, acknowledgement of your cooperation will of course be included.

Will you please send me any data pertaining specifically to qualities of the materials you manufacture and suggested retail costs of these noise absorption products. Your assistance will be greatly appreciated.

Sincerely yours,

Dale G. Smart
Research Assistant
APPENDIX C

Sample of letter to federal or state agencies:

Sirs:

I am engaged in gathering information of the attenuating properties of various materials which could be used in constructing enclosures for reduction of machinery noise.

Data available regarding the absorption qualities of construction materials such as plywood, fiberglass, plastics, lead or artificially produced materials.

This would be particularly helpful information which would be utilized with other research in developing a method for construction of noise abating enclosures. It is anticipated that these data will be analyzed and distributed to companies who are interested in constructing their own enclosures in compliance with the Occupational Safety and Health Act of 1970.

Sincerely yours,

Dale G. Smart
Research Assistant
## APPENDIX D

### Noise Survey

<table>
<thead>
<tr>
<th>Plant Location</th>
<th>Measurement Location or Operation</th>
<th>Sound Level, dBA</th>
<th>Permissible Exposure Time Per Day, Hrs*</th>
<th>Actual Exposure Time Per Day, Hrs*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
APPENDIX E

ULTRASONIC WELDING MACHINE ENCLOSURE

Plexiglass Sliding Door

$\frac{1}{2}''$ Plexiglass Face

$\frac{1}{2}''$ - $3/4''$ plywood, line with $2''$ sound absorbing tile

Allow for $2''$ overlap of Door to Plexiglass Face with door closed
Commonly Used Terms and Definitions

"A" Scale - A filtering system that has characteristics which roughly match the response characteristics of the human ear at low sound levels (below 55 dB SPL, but frequently used to gauge levels to 85 dB). "A" scale measurements are often referred to as dBA.

Acoustical Materials - Any materials considered in terms of its acoustical properties, commonly and especially a material designed to absorb sound.

"B" Scale - A filtering system with characteristics roughly matching the response characteristics of the human ear at sound levels between 55 and 85 dB. "B" scale measurements are often referred to as dBB.

"C" Scale - A filtering system with characteristics roughly matching the response characteristics of the human ear at sound levels above 85 dB. In this case, the filtering system is flat with frequency. "C" scale readings may be referred to as dBC.

Loudness - Loudness is the subjective human definition of the intensity of sound. Human reaction to sound is highly dependent on the sound pressure and frequency.

Loudness Level - A subjective method for rating loudness in which 1000 Hertz tone is varied in intensity until it is judged by
listeners to be equally as loud as a given sound sample. The loudness level in phons (cq) is taken as the sound pressure level in decibels of the 1000 Hertz tone.

Intensity Level - A measure of the acoustical power passing through a unit area expressed on a decibel scale referenced to some standard watt per square meter.

Noise - Any undesired sound usually of different frequencies resulting in an objectionable or irritating sensation.

Noise Reduction - (1) Reduction in sound pressure level caused by making some alteration to a sound source; or (2) Difference in SPL measured between two adjacent rooms caused by the transmission loss of the intervening wall.

Octave Band - A range of frequency where the highest frequency of the band is double the lowest frequency of the band. The band is usually specified by the center of frequency.

Pitch - The pitch of sound depends primarily on its frequency. In music, sounds of higher frequencies are referred to as treble notes, while those of lower frequency are referred to as bass notes.

Radiation - The process of turning structure-borne noise into airborne (or some other fluid-borne) noise.

Random Noise - Random Noise is a complex vibration made up of frequencies and amplitudes that vary with time in a random or statistical fashion.

Reverberation - Reverberation is the persistence or echoing of previously generated sound caused by reflection of acoustic
waves from the surface of enclosed spaces.

Sound - Deformation waves that are traveling in the air or other elastic materials. It should be noted that sound can be defined as the disturbances themselves or the sensations they produce.

Sound Absorption - (1) The process of dissipating or removing sound energy; or (2) The property possessed by materials, objects and structures such as rooms, of absorbing sound energy.

Sound Level Meter - An instrument for direct measurement of sound pressure levels. They are often made with various filtering networks that measure sound directly on A, B, C and other scales. Sound level meters may also incorporate octave-band filters for measuring sound directly in octave bands.

Sound Pressure - A fluctuating pressure superimposed on the static atmospheric pressure in the presence of sound. Compared with alternating voltage, its magnitude can be expressed in several ways such as instantaneous sound pressure or peak sound pressure. However, the unqualified term means root-mean-square (rms) sound pressure.

Sound Pressure Level - (SPL) A measure of the air pressure change caused by a sound wave. Expressed on a decibel scale referenced to some standard.

Wavelength - The wavelength of a sound is the distance between a point of given phase of one wave and a point of the same phase of an adjacent wave.
BIBLIOGRAPHY


