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Building Acoustics in Civil Engineering

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Abstract- The paper aims to the acoustic design feasibility study of public buildings and acoustical issues related to it. Fundamentals of acoustics, building acoustics, auditorium acoustics are familiarized. Also discussion on the necessary requirements of good acoustics, defects related to acoustics, various building acoustic materials commonly used are carried out.

Keywords: - Acoustics, Noise Level, Noise Insulation.

I. INTRODUCTION

A visually beautiful room may not be a pleasurable place to spend time due to poor building finishes. Hard flat surfaces such as wooden floors and plastered walls reflect sound thereby increasing and amplifying noise levels within the space resulting in poor architectural acoustics and sound quality. Building acoustics is the science of controlling noise within buildings. This includes minimizing noise transmission between compartments and the control of sound characteristics within a space.

The term "Building Acoustics" includes both Sound Insulation and Sound Absorption. Building acoustics can be about achieving good speech intelligibility in a theatre, restaurant or railway station, enhancing the quality of music in a concert hall or recording studio, or suppressing noise to make offices and homes more productive and pleasant place to work and live in. Building acoustic design is usually done by acoustic consultants.

II. UNITS AND IMPORTANT PARAMETERS

Sound intensity is measured in Decibels (dB). This is a logarithmic scale in which an increase of 10 dB gives an apparent doubling of loudness. Sound pitch is measured in Hertz (Hz), the standard unit for the measurement for frequency. The audible range of sound for humans is typically from 20 Hz to 20,000 Hz, although, through ageing and exposure to loud sounds the upper limit will generally decreased. As well as intensity and frequency, sound also transmits information. For example, music or speech, transmit information which people may perceive differently from other sounds.

Building acoustics can be influenced by:

- The geometry and volume of a space.
- The sound absorption, transmission and reflection characteristics of surfaces enclosing the space and within the space.
- The sound absorption, transmission and reflection characteristics of materials separating spaces.
- The generation of sound inside or outside the space.
- Airborne sound transmission.
- Impact noise.

It is very important when designing an enclosed space to ensure that no echo can occur, but reverberation happens in any enclosed space, however the reverberation time can be short or long depending upon various factors such as:

- Volume of the room Shape of the room.
- Sound absorption properties of the building elements.
- Furnishings / Objects in the room.
- Occupancy of the room.

III. BUILDING ISOLATION & NOISE TRANSMISSION

There are four major actions which can be taken to improve noise compatibility for any type of land use or activity. These are site planning, architectural design, construction methods, and barrier construction.

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Acoustical site design uses the arrangement of buildings on a tract of land to minimize noise impacts by capitalizing on the site's natural shape and contours. Open space, nonresidential land uses, and barrier buildings can be arranged to shield residential areas or other noise sensitive activities from noise, and residences can be oriented away from noise.

Acoustical architectural design incorporates noise reducing concepts in the details of individual buildings. The areas of architectural concern include building height, room arrangement, window placement, and balcony and courtyard design.

Acoustical construction involves the use of building materials and techniques to reduce noise transmission through walls, windows, doors, ceilings, and floors. This area includes many of the new and traditional "soundproofing" concepts.

Noise barriers can be erected between noise sources and noise-sensitive areas. Barrier types include berms made of sloping mounds of earth, walls and fences constructed of a variety of materials, thick plantings of trees and shrubs, and combinations of these materials.

IV. ROOM ARRANGEMENT

Noise impacts can be substantially reduced by separating more noise sensitive rooms from less noise sensitive rooms; and placing the former in the part of the building which is furthest away from the noise source. The less sensitive rooms should then be placed closest to the noise source where they can act as noise buffers for the more sensitive rooms.

Whether or not a room is noise sensitive depends on its use. Bedrooms, living rooms, and dining rooms are usually noise sensitive, while kitchens, bathrooms, and playrooms are less so. Fig. 3.1shows a layout designed to reduce the impact of highway noise. This technique was used extensively in England in a 100 acre residential development adjacent to a planned expressway.

Kitchens and bathrooms were placed on the expressway side of the building, and bedrooms and living rooms were placed on the shielded side. In addition, the wall facing the expressway is sound insulated.

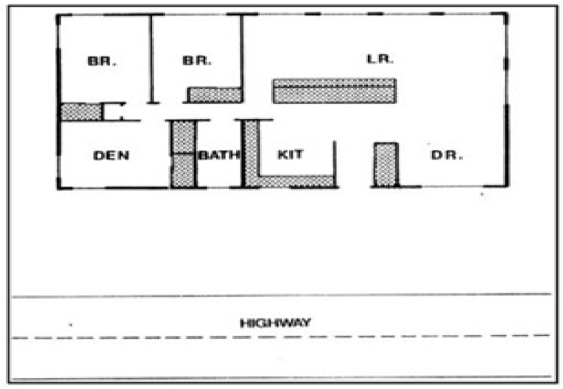

Fig 1. Use of acoustical architectural design to reduce noise impacts.

1. Balconies:

If balconies are desired they should be given acoustical consideration. The standard jutting balcony, facing the road, may reflect traffic noise directly into the interior of the building in the manner illustrated in Figure 3.2. In addition to reflecting noise into the building, the balcony may be rendered unusable due to the high noise levels. This problem is particularly applicable to high rise apartment buildings where balconies are common. If balconies are desired, the architect may avoid unpleasant noise impacts by placing them on the shielded side of the buildings.

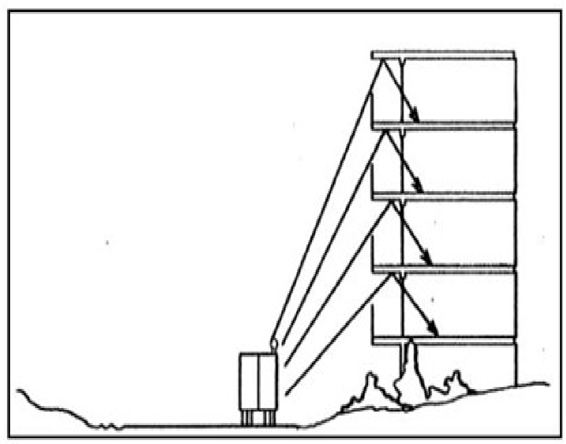

Fig 2. The standard jutting balcony reflects noise to the interior.

2. Courtyards:

Proper architectural design may also provide for noise reduction in an area outside of the building. The court garden and patio houses can provide outdoor acoustical privacy (Fig. 3.3). Schools, rest homes, hotels, and multi-family apartment dwellings can also have exterior spaces with reduced noise by means of court yards.

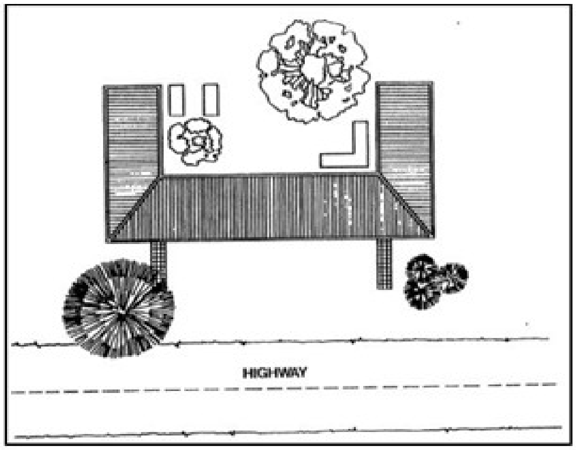

Fig 3. Use of courtyard house to obtain quite outdoor environment.

3. Sabine's Formula:
One of the most reliable ways of knowing the reverberation time of your space before building is by using the complex three dimensional architectural and acoustical modeling and measuring technologies. For acoustically critical venues, even a physical model of the building and its interiors may be required. But, for many regular shaped and normal sized rooms, a simple Sabine equation may give you a quick estimation of the reverberation time.

According to the European Standard EN 12354-6:2003 Building Acoustics-Estimation of acoustic performance of buildings from the performance of elements-Part 6: Sound absorption in enclosed spaces, Sabine formula can be used to estimate the reverberation time of an enclosed space with:

- **Regular shaped volume:** no dimension being more than 5 times of any other dimension;
- **Evenly distributed absorption:** absorption coefficients not varying by more than a factor of 3 between pairs of opposite surfaces, unless good sound diffusion objects are present;
- **Not too many objects:** total volume of objects being less than or equal to 20% of room volume.

Sabine's formula is given by the following:

$$\mathbf{RT_{60} = \frac{24\,(ln10)\,V}{C_{20}\,S_a} = 0.049\frac{V}{S_a}}$$

Where;
RT_{60}= is the reverberation time (to drop 60 dB)
V= is the volume of the room
c_{20} =is the speed of sound at 20°C (room temperature)
S_a =is the total absorption in Sabin's

The absorption coefficient has a range of 0 to 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 sabin, named in honor of Wallace Sabine, is a unit of measure; one imperial sabin equals one square foot of 100% absorbing material, and one metric sabin equals one square meter of 100% absorbing material. Stemming from Sabine's 19th century work a new field of study was born. Today, computer programs incorporate Sabine's formula to help engineers and architects model and design future concert and lecture halls around the globe.

V. ACOUSTIC MATERIALS

To compare the insulation performance of alternative constructions, the Sound Transmission Class (STC) is used as a measure of a material's ability to reduce sound. Sound Transmission Class is equal to the number of decibels a sound is reduced as it passes through a material. Thus, a high STC rating indicates a good insulating material.

It takes into account the influence of different frequencies on sound transmission, but essentially it is the difference between the sound levels on the side of the partition where the noise originates and the side where it is received. The Sound Transmission Class rating is the official rating endorsed by the American Society of Testing and Measurement.

It can be used as a guide in determining what type of construction is needed to reduce noise.

1. Acoustical Blankets:
Also known as isolation blankets, these can increase sound attenuation when placed in the airspace. Made from sound absorbing materials such as mineral or rock wool, fiberglass, hair felt or wood fibers, these can attenuate noise as much as 10 dB. They are mainly effective in relatively lightweight construction.

2. Basotect:

Basotect is light weight open cell foam, which is made from melamine resin. It is flexible, easy to handle, cut and install. It is available in sheet form and also available in pre-cut or profiled to size and shape. The natural color of the foam is light grey, although it is also available in a range of functional or decorative facings and fabrics that can he sprayed with flexible PVC coating. It is designed for use in thermal and acoustic insulation applications.

3. Sound Fibre-Poly:

It is manufactured from non-irritating water repellent polyester fibers. It is designed for use in acoustic and thermal insulation applications. It can be supplied in sheet form in packs 10 or cut to a specific size and shape. It can also be supplied in fabric wrapped form for architectural applications or with other performances enchanting facings.

4. Sound Foam, 0:

It is flexible open cell polyurethane foam, offering excellent sound absorbing qualities over wide range frequencies. It is available plain or self- adhesive backed. It is easy to handle and to cut and install. It is black non-flammable acoustic foam. It is impregnated with fire retardant chemicals which enables the material to achieve class '0' fire rating as defined by the building regulations. It is extensively used in air conditioning and air handling system, ducting and also compressors, generators, enclosures and other applications.

Materials	Absorption coefficients by frequency (Hz)				
	125	250	500	1,000	2,000
Acoustic tile (ceiling)	.80	.90	.90	.95	.90
Brick	.03	.03	.03	.04	.05
Carpet over concrete	.08	.25	.60	.70	.72
Heavy curtains	.15	.35	.55	.75	.70
Marble	.01	.01	.01	.01	.02
Painted concrete	.10	.05	.06	.07	.09
Plaster on concrete	.10	.10	.08	.05	.05
Plywood on studs	.30	.20	.15	.10	.09
Smooth concrete	.01	.01	.01	.02	.02
Wood floor	.15	.11	.10	.07	.06

Fig 4. Absorption Coefficients of Common Materials.

Most common application areas of Acoustic Material:

- Home theatre acoustics.
- Wall sound proofing.
- Ceiling sound proofing.
- Studio Acoustics.
- Floor and football sound proofing.
- Office and conference room acoustics.
- Industrial acoustics.
- Pipe sound proofing.
- Church and place of worship acoustics.
- Restaurant and lounge acoustics.

VI. CASE STUDY

1. Site Selection:

An ideal site should keep distance from any major sources of noise such as airports, highways and construction sites. The surrounding buildings and topography may also act as obstructions to sound waves and affect the overall acoustics of the building. The site we selected was an auditorium which is a public building under 9B classification. The site is located in a silent space surrounded by open natural spaces. Two site visits were conducted to obtain material finish data and to carry out preliminary engineering survey at site. Engineering drawings were also created for reference.

2. Primary Investigations:

The engineering drawing of existing auditorium building was collected and preliminary survey was carried out using tape and laser instruments. The dimension of the auditorium hall is 54.14m x 15.90m x 12.00m as measured using a measuring tape and a laser equipment (to measure the height). The flooring provided is synthetic type flooring. The ceiling includes perforated gypsum boards and the walls are plain cement painted.

There are sixty numbers of open windows and five doors throughout the auditorium. Doors at the main entrance are metallic while open exits are provided at the backside of the auditorium. First floor is back open and seating is also provided only at the backside of the auditorium. Windows and ventilations are grilled using steel. Curtains are also provided made of polyester fabric. Seats are fixed only at first floor which is also metallic. No fixed seats are provided at ground floor as the hall is used for badminton court as assumed. There is an open space at the backside of the auditorium which is connected to the first floor.

Stairways are provided at the exit of the backside which leads to the first floor seating. While stairs are also provided at the main entrance to access the top floor. Engineering drawings of the auditorium were produced using AutoCAD software.

VII. ACOUSTIC INSTRUMENTS

A sound level meter is used for acoustic (sound that travels through air) measurements. It is commonly a hand-held instrument with a microphone. The best type of microphone for sound level meters is the condenser microphone, which combines precision with stability and reliability.

The diaphragm of the microphone responds to changes in air pressure caused by sound waves. That is why the instrument is sometimes referred to as a Sound Pressure Level (SPL) Meter. This movement of the diaphragm, i.e. the sound pressure deviation (Pascal Pa), is converted into an electrical signal (volts V).

While describing sound in terms of sound pressure (Pascal) is possible, a logarithmic conversion is usually applied and the sound pressure level is stated instead, with 0 dB SPL equal to 20 micro pascals.Decibel measurements are obtained by using the Sound Level Meter. The microphone converts fluctuating air pressure produced by a sound source into a fluctuating electrical charge. That electrical charge is then converted by the input amplifier into a voltage that, once processed by the electrical circuitry, is converted into a sound pressure level (SPL). The output amplifier then converts the weak sound signal to a level adequate to display on the read out panel.

Finally, the read out panel displays the average sound pressure levels for the environment being analyzed. Filters can be used by the meters to measure specific bands of sound wave pressure by honing in on specific frequencies within a larger sound escape.

Some advanced sound level meters can also include reverberation time (RT60) (a measure of the time required for the sound to "fade away" in an enclosed area after the source of the sound has stopped) measurement capabilities.

The performance of a loudspeaker/listening room combination really matters, as the two interact in multiple ways. There are two approaches to high-quality reproduction. One ensures the listening room be reasonably 'alive' with reverberant sound at all frequencies, in which case the speakers should ideally have equal dispersion at all frequencies in order to equally excite the reverberant fields created by reflections off room surfaces.

The other attempts to arrange the listening room to be 'dead' acoustically, leaving indirect sound to the dispersion of the speakers need only be sufficient to cover the listening positions. Loudspeaker acoustics is a subfield of acoustical engineering concerned with the reproduction of sound and the parameters involved in doing so in actual equipment.

VIII. SOUND TEST METHOD

In atmospheric sounding and noise pollution, ambient noise level (sometimes called background noise level, reference sound level, or room noise level) is the background sound pressure level at a given location, normally specified as a reference level to study a new intrusive sound source.

Ambient sound levels are often measured in order to map sound conditions over a spatial regime to understand their variation with locale. In this case the product of the investigation is a sound level contour map. Alternatively ambient noise levels may be measured to provide a reference point for analyzing an intrusive sound to a given environment.

Sound tests were conducted using XL2 Data Analyzer by producing pink noise spectrum from loud speakers. This acoustic quality can be characterized based on the reverberation time (RT), speech transmission index (STI) and the sound insulation.

The investigation used acoustic measurement methods to assess the acoustic quality of the nave and the results were compared with the standards ISO 3382-1 and ISO 3382-2.

The results of this work were obtained by measuring the RT values and the sound insulation of auditorium façades. In addition to these parameters obtained by measurements, STI was obtained through the computer simulation. The results showed that the measured and calculated values were consistent with those proposed by the standards for speech auditoria (RT500Hz = 0.98 s, D50> 50% and STI> 0.45), and are in line with the speech intelligibility requirements.

IX. SOUND TEST RESULTS

It was noted that every value exceeded the standard limits for achieving a good acoustic auditorium hall. The primary and significant factor that narrows the sound quality of our site was the Reverberation Time. Its value as recorded is very poor (high) to perform acoustical quality.

According to Sabine, the frequency dependent reverberation time of a room is usually given for the center of a third octave band filter frequency of 500 Hz or 1 kHz or a frequency dependent response curve of the reverberation time of the frequency, but this is not a "frequency response" of the reverberation.

So, RT60 value at 500Hz was taken as Reference Frequency for RT calculation. Thus, the peak value obtained at site was noted as 2.45s.. The STC rating of existing door is 23.5, which is very poor to perform good acoustical quality for the auditorium. The same value was obtained from test data of Sound Level Meter.

X. ACOUSTICAL TREATMENT

Acoustical treatment is required on ceiling as well as on walls to achieve the sound quality requirements. 10mm carpeted floor option is recommended to produce significant reduction in reverberation time which improves the speech intelligibility inside the auditorium. Ceiling and walls are to be installed with Echo soft Acoustic panels of 50mm thickness.

The overall modification will make the auditorium acoustically sound, however not completely meeting the standards due to existing conditions. So, another option has to be made to bring the best acoustical performance which was also studied in this project.

An additional material was installed to reach the standard criterion; which is to bring the reverberation time to 1.5s for obtaining a good acoustical auditorium. The material which we used in addition is to lay insulation foams beneath the carpet flooring.

We tried to ensure that our treatment recommendations are efficient, durable and economical thus making it best possibility of our study. The insulation foams are cheaper and economical than any other material. They also provide soothing effect to the audience occupying the hall.

The efficiency of foams is also remarkable from their sound absorption coefficients which reduce the RT60 from 1.58s in Option A to 1.51s in Option B.

Calculation using Sabine's formula

According to Sabine's formula, reverberation time be calculated as,

$$RT = 0.163 * V/SA$$

V= Room Volume= 54.14mx15.90mx12.00m =10,330 cubic meters.
SA = Surface Area

The value of reverberation time in existing condition, after acoustical treatment with and without underlay were calculated and obtained as below.

- RT = 0.163*10,330/647.53 = 2.60032s
- RT = 0.163*10,330/1,064.62= 1.58158s
- RT = 0.163*10,330/1,112.62= 1.51335s

XI. CONCLUSIONS

Scope of acoustics and its importance in the field of civil engineering are studied in this paper. The need for acoustics in buildings is to a great extend The fundamental concepts of acoustics, general requirements for a good acoustic room, various defects in acoustics and common acoustic materials used in construction were also familiarized.

A case study was conducted in an auditorium to study different acoustical properties as well as the important parameters affecting building acoustics. Manual calculation using Sabine's formula gives the value of reverberation time inside the room from combined room absorption values data. The obtained value was verified with the existing software used in acoustics design.

Since one of the main goals of architectural acoustics is to provide optimum speech intelligibility and sound quality in auditoriums of public buildings, acoustical input is required in the construction of new buildings and during the refurbishment of existing buildings whether they are general purpose or specialized facilities.

The acoustical inputs therefore include the use of materials that can ensure good absorption, reflection, transmission and diffusion of sound in order to eliminate the problems of reverberation and echoes and achieve an equal sensory of sound by an audience at different locations within the hall.

It is recommended that an acoustician be consulted for professional advice on design and the use of materials that have good acoustic properties in order to help optimize acoustics since the success of an acoustical design depends to a considerable extent upon how completely the acoustician's recommendations are followed in carrying out the design.

Ignoring, or partial acceptance of recommendations usually leads to acoustical deficiencies in the hall. Choosing the most suitable materials aids the overall noise control of the building and creates a conductive environment for event hosting. Consideration must also be taken on the type and position of speakers in the hall as a vital factor on the overall acoustical control achieved. The desired optimum reverberation time of 0.9s is perfect for a speech-based auditorium, while still being suitable for musical performances which were a regular feature in the auditorium.

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