Acoustical analysis of Kennedy auditorium, India

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Abstract

The study of Architectural Acoustics involves the understanding of sound build up and its propagation in a simple room. This knowledge can be further applied to larger rooms and performance areas such as concert halls, theaters and sports arenas. The basic acoustic parameters that govern the quality and intelligibility of sound for the listeners as well as the performers are needed to be evaluated. This helps the acousticians to classify a performance venue as poor or lively in terms of the spaciousness of sound. The acoustic measurements are therefore necessary to evaluate these parameters and find out the behavior of sound in certain spaces of a Concert Hall or any performance venue. This paper presents an acoustic analysis of Kennedy Auditorium with the active sound systems in use. Further, the effect of the Building materials and their absorption properties has been explained in detail.

Keywords: architectural acoustics, acoustic measurements
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1 Introduction

Kennedy auditorium, a part of Cultural and educational Centre, Aligarh Muslim University, is one of the heritage buildings of India. The auditorium was constructed in 1962 and was named after the US President John F. Kennedy. With the capacity of 1650, Kennedy Auditorium is host to conferences, debate competitions, drama, musical theatre, and concerts. The seating arrangement is in curvilinear fashion. The seating pattern of the auditorium is designed on the basis of constant rise method and is fractured into two tiers - ground floor seating and balcony seating. Ground floor can accommodate 1360 people while balcony can cater for 290 more. The stage is almost circular and is 25m in width. It is comprised of two rotating type stages (not functional currently). The front portion of the stage is curved and the back portion is semi octagonal. At present, there is no reflecting surface in this auditorium, no absorbers and no diffusers. Since 1962, no acoustical treatment has been done on this auditorium.

Figure 1: Seating view from the Stage

The acoustical properties of Kennedy Auditorium have been characterized on the basis of four main acoustic parameters, namely, Reverberation time (RT), Clarity, Early Lateral Energy and SPL Distribution. Taking various considerations into account the computer simulation have been performed using commercial software on the actual 3D model of the auditorium and acoustic parameters are calculated for different sound source and receiver positions.

The RT has come out to be 4.6s with seating occupied by audience and 6s without the audience- a much higher value of RT then what is generally required for concert halls or auditorium. The existing infrastructure of the auditorium involves various issues related to building acoustics such as high RT and no acoustical treatment done on the walls and other
visible surfaces that cause abrupt reflections while a sound source is active. The renovation and renovation and improvisation of Kennedy Auditorium is under process and will be carried out in two phases. Through this paper we are dealing with the phase-I which is concerned with the acoustical design recommendations and alterations after simulation.

A lot of study and experimental work has been done to define the best suitable RT for different halls. For concert halls that host live rock and pop music a detailed survey of 20 rock music venues was conducted [1]. The value of RT was taken to be 0.6s to 1.2s for hall volumes from 1000m³ to 6000m³[2]. The room acoustics of a given chamber dictate the effectiveness of aural communication within it. The goal of architectural acoustics is to maximize this effectiveness through the study and manipulation of a room’s acoustical properties. Most often, this process consists of the reduction of unwanted noise and the enhancement of deliberate sound through electronic amplification. Any noise which is present will counteract this signal, making it less audible and acoustically unsatisfactory. The ability to control this signal to noise ratio is therefore a necessity.

![Figure 2: Side view showing no treatment on walls and the Trusses supporting the Ceiling](image)

2 Room parameters

Reverberation in acoustics or psycho acoustics is the persistence of sound after being produced. This is undesired when the direct sound dies, but the reflections are audible with continuous decreasing amplitude, due to interaction with various room surfaces. The time taken for these reflections to die is indicated as RT. Eyring developed a relation between RT60, the room volume and room absorption [3].

\[ RT_{60} = 0.16 \frac{V}{S \ln(1-a)} \]
Where $V =$ Total Room Volume, $S =$ absorptive surface area, $\bar{\alpha} =$ Average Absorption Coefficient. Sound pressure level, SPL or acoustic pressure level is a logarithmic measure of the effective pressure of a sound relative to a reference value. SPL, denoted by $L_p$ and measured in dB, is defined by

$$L_p = 20 \log_{10} \left( \frac{P}{P_0} \right) \text{ dB}$$ (2)

Where $p =$ SPL at any position measured from the sound source, $P_0 =$ SPL at the source.

Speech Transmissibility Index, STI is the measure of speech transmission quality. It is measured on the scale of 0 to 1. It is given by

$$STI = \frac{S + 15}{30}$$ (3)

Here ($S/N$) is the signal to noise ratio. In the late 1960s, Harold Marshall discovered that early reflections arriving from lateral directions created a desirable sense of spaciousness [4]. Here, the initial time interval in the numerator is taken to be slightly greater than 0s since the early reflections cannot begin simultaneously with the direct sound.

$$LF = \frac{\int_0^{0.05} p(t) dt}{\int_0^{0.05} P(t) dt}$$ (4)

Similar calculations for Lateral Energy Fraction, LF are made for time intervals of 7ms and 80ms, depending upon the time gap being used to calculate the energy due to early reflections. These are denoted as LF7 or LF80. $C_{50}$ is used to project speech intelligibility. It displays the ratio of energy before and after 50ms. Any value above 0dB in a room with normal reverberation represents good intelligibility. In rooms with higher than normal reverberation, any value above 5dB is considered good [5].

$$C_{50} = 10 \log \frac{\int_0^{0.05} p(t) dt}{\int_0^{0.05} p(t) dt}$$ (5)

Where $P_L =$ SPL at the sound source, $t =$ time interval in seconds.

### 3 Acoustic Simulations

The propagation of sound can be modeled the same way we can model light, with a ray: a linear displacement of energy which travels with the speed of sound in air in the direction perpendicular to the wave front. The ray itself has no dimension. It is infinitely thin and has only a displacement with a certain direction [6]. When a reflection is detected at a room boundary, secondary sources are created distributed over the surface. From these secondary sources a ray-tracing is started. For the receivers visible to the secondary sources, several low energy contributions are made in time. Nowadays there are several computer programs commercially available with which room acoustic parameters can be predicted on the basis of ray-tracing.
Figure 3 : 3D view of the Kennedy Auditorium

The figure above shows the 3D drawing of the auditorium. The sound source with a maximum SPL of 115dB is placed above the center of the proscenium. It is shown by a red dot. The spaces marked with green solid triangles are the listener positions at which different acoustic calculations have been performed. The coordinates of these points in (x,y,z) m are Position 1 (1,-34,2), Position 2 (8,-45,4,2) and Position 3 (9,-44,8) at the Balcony. The variation for RT has been shown with and without the audience layers in Figure 4.

4 Materials used

The existing materials of Kennedy auditorium are discussed in this section. They offer some acoustical properties to the hall which without any sound reinforcement system provides a required level of clarity.

Two different considerations have been taken for the audience area; one in which there is no seating and the other where there is public seating. Since the audience area has the maximum area right in front of the public address (PA) system, its acoustical properties have a major effect on the RT and STI values.

Effort is made to choose the seat absorption value such that even without a full house situation the change in RT is not significant. It is typical of the Kennedy Hall that the acoustic parameters change significantly when it is filled with people, which is characteristic of such halls with a relatively high reverberation time, for example, Grosser Musikvereinssaal, Vienna [7].

The stage has hardwood flooring on beams which offer little absorption to the low frequencies. The stage ceiling is also at 10% absorption like the ceiling of the rest of the auditorium, though it is at a lower height. The side walls are of 400mm thick brick with unglazed painting over them. They have almost negligible absorption. The back wall, under the Balcony has a 35/15mm
The area covered by doors has a 1-3/4inch solid core wood.

5 Results and Discussion

It can be observed that for unoccupied seating RT is higher at low frequencies. There is a considerable reduction in its value for fully occupied seating where the RT drops from 6.12s to 4.18s. This is due to increase in absorption with the audience present in the hall.

The values of STI were found to be in the range of 0.43 to 0.58 as shown in Table 1 which is a considerable value for concert halls with high reverberance present.
The total SPL in Figure 5 for both the cases is found to be more at the front position (Position 1) as it is close to the sound source hence the direct SPL is higher. For unoccupied seating the maximum value is more due to less absorption and higher reflection density in the empty space.

![Figure 5: Total SPL (Occupied/Unoccupied)](image)

The values for C50 and L50 are given in the table below at different frequencies for both occupied and unoccupied seating.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>250</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>1 2</td>
<td>1</td>
</tr>
<tr>
<td>C50 (dB)</td>
<td>-4.64</td>
<td>-12.38</td>
</tr>
<tr>
<td>L50 (dB)</td>
<td>104.57</td>
<td>96.88</td>
</tr>
<tr>
<td>Unoccupied</td>
<td>102.2</td>
<td>99.01</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>Position</td>
<td>1 2</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2 : Values for C50 and L50
<table>
<thead>
<tr>
<th>C50 (dB)</th>
<th>Occupied</th>
<th>Unoccupied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.08</td>
<td>-2.7</td>
</tr>
<tr>
<td></td>
<td>-0.29</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>-4.25</td>
<td>-6.94</td>
</tr>
<tr>
<td></td>
<td>1.72</td>
<td>-1.93</td>
</tr>
<tr>
<td></td>
<td>0.81</td>
<td>-2.77</td>
</tr>
<tr>
<td></td>
<td>-3.22</td>
<td>-5.98</td>
</tr>
<tr>
<td>L50 (dB)</td>
<td>Occupied</td>
<td>Unoccupied</td>
</tr>
<tr>
<td></td>
<td>109.07</td>
<td>107.12</td>
</tr>
<tr>
<td></td>
<td>107.14</td>
<td>106.54</td>
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<tr>
<td></td>
<td>103.27</td>
<td>103.23</td>
</tr>
<tr>
<td></td>
<td>106.75</td>
<td>105.54</td>
</tr>
<tr>
<td></td>
<td>105.07</td>
<td>104.41</td>
</tr>
<tr>
<td></td>
<td>101.16</td>
<td>101.71</td>
</tr>
</tbody>
</table>

There are two observations that can be made from the table 2. First, the value for C50 is much more acceptable for fully occupied seating as the audience is absorbing the late reflections to a certain extent. The second one is the highly negative value of C50 in the balcony area (Position 3). This is the result of high reverberant energy field being present near the ceiling due to the higher reflection density. Since the reverberation is more at low frequency, it is more negative at 250 Hz as compared to 1000Hz.

The Early Lateral Energy (L50) has an appreciable magnitude that is varying from 101 to 109 dB considering that the sound source has a maximum SPL value of 115 dB. The lateral reflections are possible due to the larger surface area of the side walls that have a very low absorption value.

### 6 Conclusions

The RT of the Auditorium is much larger than the accepted values especially at lower frequencies. The side walls are highly reflecting in nature and proper wall treatment is required for trapping the lower frequency reverberance. The existing sound system in the hall has to be optimized by proper installation of line arrays and infra subs.

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### References


