CROWD NOISE MEASUREMENTS AND SIMULATION IN LARGE STADIUM USING BEAMFORMING

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ABSTRACT

The noise generated by the crowds and organized fans during sporting events has created a challenge for the sport facility management. The new demand for full compliance to National Football League rules on crowd noise, and cities' regulations on noise ordinance require new methods or approaches in measuring such environmental conditions. Given their dynamic range and possible classification, noise levels generated by large crowds has impacted the outcome of games, and recent analysis of the available data shows an increase in noise related penalties. This situation has provided more excitement for the spectators and greater participation in the events, however sound intensity of 95 to 110dBA is now the typically reported range of recorded noise levels within various sport arenas.

This paper describes a new approach in measuring crowd noise, and estimating the contribution of various frequency ranges for evaluation of the existing, and in this case, the proposed University of Michigan newly designed addition of sky boxes to the football stadium. Data was measured using Acoustic Camera spherical array, 120 channel data recorder, and utilizing various acoustic software for data reduction, computer modeling, simulation and analysis. The measured and simulated results based on these parametric studies are compared against selected well known stadiums for their crowd noise conditions. The frequency domain and spectral analysis are used as input to the computer modeling, simulation and analysis of the space. Using newly developed room acoustic indicators provide a new approach in estimating the impact of the reflected sound contribution to the crowd noise; given the sky boxes as part of the new addition with their unique facade and window geometry.

1 INTRODUCTION

Architecturally speaking, not all stadiums are designed equally since the space geometry for each sport varies given the required acoustic performance. The desired crowd noise is not loud enough because the vocal cords are not strong enough, and or the fans are not large in number, or they do not react in harmony. National Football League in USA has had an uncomfortable position with the crowd noise issue, and may soon rely on a wireless communication system designed within the players helmet to over come this noise issue **[1-2].** Noise is defined as unwanted sound, however in sport entertainment, this definition does not hold to be true by the fans. The ear can just distinguish a difference of loudness between two noise sources when the there is a 3dBA difference between them, and when the two sound sources of the same pressure level and frequency are combined. The resultant level is considered twice as loud when the two sounds differ by 10 dBA. Architectural Acoustic discipline requires designers to estimate the reverberation time as one of the indexes for room acoustic studies. Acoustic performance evaluation of various stadiums shows that the reverberation time varies for low, mid and high frequencies. Reverb time is define as the time in seconds that it takes for the sound to drop off to a point 60dBA below the starting sound, and it is shown as RT60 or T60. Most reported RT are for 500Hz or average of 500 and IK. Measured data for 250 Hz and lower are not reliable, and calculated results at early stage of the design are good enough to 125 Hz only, given the feed back from acoustic society members and published data **[3-5].**

2 METHODOLOGY

Current architectural practice for stadium design has to rely on diffused sound filed conditions. Applying statistical methods where the absorption coefficient is weighted by the surface area, and the number of sound rays hitting each surface is used to estimate the contribution of each surface absorption at each frequency range. The average absorption is then used along with effective Volume (V) calculated from mean free sound path length and surface area using the statistical RT equations shown below.

Once the Average Coefficient (Avg_Coeff) is calculated for each frequency band (i), this can be multiplied by the total exposed surface Area (A) for each method such that:

RT60 $_{\textbf{Sabine}}$ = (0.161 * Volume) / (Area * Avg Coeff [i]); **Equation (1)**

RT60 $_{\textbf{Norris}}$ = (0.161 * Volume) / (-1 * Area*log(1-Avg Coeff [i])); **Equation (2)**

RT60 $_{\textbf{Millington}}$ = (0.161 * Volume) / (Area*(ms[i]/ms_Ray hits [i])); **Equation (3)**

The Millington-Sette calculation indicates the hit ratio for each individual surface, where for each object: ms[i]+ = (-1 * Ray hits * Log(1 - abs)) ;ms_Ray hits[i] += total_Ray hits;

Statistical methods do not show individual contribution due to physical geometry, however the estimations of the count number of hits on each surface give the absorption coefficients for each frequency range, and provide a better overall sound experience in the space. These procedures are used to estimate the RT and sound decays for the UM stadium, and the results are compared against measured data with similar large scale sport arenas within USA **[4,6-9]**

2.1 Application of EDT, RT and BR

Bass Ratio (BR) is defined as averaged Early Decay Tim (EDT) of 125 and 250 divided by the averaged EDT of 500 and 1KH, however the EDT is for 10dBA of sound energy decay, and since it does not include the reflection it will not be as useful for the large arenas. Bass ratio using RT60 is also used to show the performance of the large scale music halls. Typical BR for small halls reaches 1 or unity, and the BR for large size concert halls is between 1.1 and 1.2. Given the demand for evaluation of the crowd noise for various venues in stadiums, there is a need for accurate low and mid frequency measurements. Using the reported data on various well known stadiums, the BR were calculated using TR60 data, and the results show that using the "Low" and "Extended Low" frequency in BR calculation do represent the contribution from the reflected components from the surrounding surfaces within the stadiums. The calculated and measured RT using the TEF system for selected stadiums for six different octave center frequency of 125, 250, 500, 1K , 2K and 4K range from bass to treble tones are shown in **Table 1.** The RT in large stadiums varies from 5 to 7 for mid frequency, 7 to10 for low and 15 to 20 for extended low frequency by including 63 Hz. The differences in low and mid frequencies shown in Table 1 are more obvious for stadiums with data on open and closed roof settings, also the correlation between the BR and the extended BR for similar bands of frequencies.

Table 1. *Reported measurements of RT 60 by [3] using TEF system and the calculated Bass Ratios.*

USA Selected Stadium	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	Ex Low Freq.Avg	Low Freq.Avg	Mid Freq.Avg	Bass Ratio	Ex Bass
Astrodome Huston TX (1988)	**17.65**	11.4	6.47	5.38	4.72	4	2.85	11.84	8.94	5.05	**1.77**	**2.34**
Bankone ball park Phoenix AZ-closed		**8.56**	**7.6**	**6.03**	**5.47**	**4.59**	**2.29**		**8.08**	**5.75**		
Bankone ball park Phoenix AZ -open		**5.73**	**5.54**	**4.93**	**4.65**	**3.96**	**2.29**		**5.64**	**4.79**		
Kingdome seattle WA 1994	**22.5**	18.8	11.3	6.03	5.2	4.3	3.1	17.53	15.05	5.62	**2.68**	**3.12**
Miller park Milwakii W (roof Closed)		15.25	12.33	9.15	7.05	4.45	3.36		13.79	8.10		
Safeco Park Field seattle WA (roof Closed)		**19.21**	**12.5**	**8.09**	**5.05**	**6.5**	**4.49**		**15.86**	**6.57**		
Baleco Park Field seattle WA (roof open)		**5.13**	**3.3**	**4.09**	**4.73**	**4.16**	**3**		**4.22**	**4.41**		
Silverdome Pontiac MI		5.4	6.3	9.7	9.3	8.3	3.5		5.85	9.50		
Superdome New Orleans LA	**7.4**	7.2	6	6	5.95	5	4.6	6.87	6.60	5.98	**1.10**	**0.72**
Texas stadium Dallas TX	**12.5**	12	11.5	7.5	6.5	5.5	4.25	12.00	11.75	7.00	**1.68**	**2.01**
AVERGAE Measured USA selected Stadiums	**15.01**	**10.87**	**8.28**	**6.69**	**5.86**	**5.08**	**3.37**	**12.06**	**9.58**	**6.28**	**1.53**	**1.92**

2.2 Application of Acoustic Camera

Acoustic Camera was used to measure from both center and side filed positions within the UM stadium. The system produces images of sound sources or “localizes” sound sources using the Beam forming technique. The acoustic images consist of color contours indicating where the most significant noise sources are located. Detailed review of this technique are described in References **[10,11].** The system consists of a microphone array with camera, data recorder, and Noise Image software running on a laptop PC. **Fig. 1** shows the typical system components used by Acoustics Camera and the actual setting for crowd noise measurements within the UM stadium during the game. The net result from the system is a sound image superimposed onto a 3-D CAD model for specific application. Data can be analyzed for specific time periods and frequency ranges allowing results to be correlated with standard architectural acoustic measures. The objective of this study is not only to visualize the noise performance of the space for validation and or correlations of computer simulations results, but also to produce a protocol for future on site data collection given the dynamic frequency of the crowd noise.

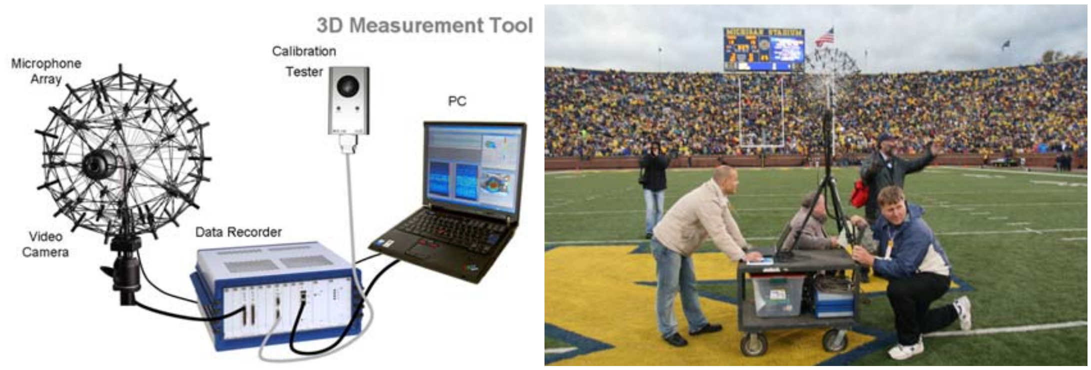

Fig. 1. Recording system and actual experimental set up for measurements within the UM stadium.

3 RESULTS

The addition of luxury boxes to Michigan Stadium and their unique design and building geometry will make a contribution to the so called desired crowd noise or louder "Big House" acoustic by the fans according to tests results and real time measured data during the game. During halftime at a Saturday football game against Minnesota, the sound in Michigan Stadium at the 50-yard line was measured to predict what impact the planned renovations will have in making the stadium louder. The measured results were used as an input in computer simulation modeling for various parametric studies.

The 120 small microphones record the crowd noise within playing field. The software allows the user to pinpoint exactly how much sound individual people and musical instruments make in a crowd of a hundred thousand. Other factors such as the duration of the yells from the crowd, and the length of time it takes for the crowd to reach "full loudness", the point at which the noise intensity level remains steady, had to be evaluated for peak measurements, and their spectral characteristics. Crowd participation was almost entirely controlled by the student section and their effort. If all 109,840 individuals had yelled at the same intensity, the measurement would have increased to 102 or 103 dBA, $L_{\mathbf{eq.(10)}}$ within the center of the open top field, which is a significant sound increase. Digital recording of the data measured within the UM football center or side field are shown in **Fig. 2**. Also the spectators' peak noise as time series data measured during the length of a game at various sound level thresholds of 100, 90 and 80 is shown in RGB colours respectively.

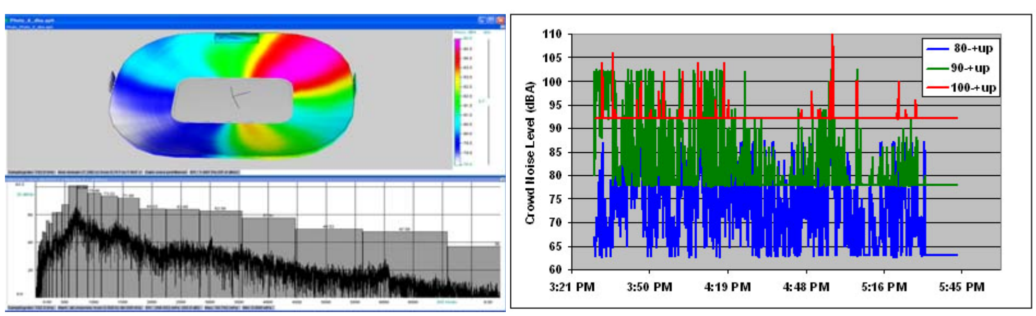

Fig. 2. Sound image of the crowd noise, peak frequency and the time series measured in stadium.

4 ANALYSIS

Acoustic Camera data was post processed to produce Acoustic Photos for each crowd noise condition and measurement position. The methodology and calculation procedures were applied for the UM stadium with and without the sky boxes. Each sound source and intensity was simulated using the Acoustic Camera data. The sound recording was generated taking the crowd noise into account by using sound from prior to the start until after the sound reverberation had stopped. An Acoustic Photo was generated for as many locations and time intervals required for these computer simulations. These simulations uses 3D acoustic views and the dynamics of the sound rays within the space during the steady state behavior, this visualization of the sound field as it interacts with the interior surfaces of the space allows the calculation of time histories for specific points of interest in the space. This data can then be used to correlate the UM model for acoustic metrics in a space based methodology. The 3D acoustic models of these simulations are shown in **Fig. 3**. The early decay and the RT60 were calculated using equations 1 through 3, and the results of various Bass Ratios using low and extended low frequencies are shown in **Table 2.** Comparisons with the average indexes of other well known stadiums are shown in **Fig 4**. The larger extended BR (almost by 1 second) calculated using RT60 $_{\mathbf{Millington}}$ equation indicates reflected sound contributions from the new sky boxes facades and or operable windows are much higher to the playing field **[6-9].**

Table 2. *Calculated RTs 60 and the relates low and extended low frequency Bass Ratios.*

UM- Stadium	63Hz:	125Hz:	250Hz:	500Hz:	1kHz:	2kHz:	4kHz:	Ex Low Freq.Avg	Low Freq.Avg	Mid Freq.Avg	Bass Ratio	Ex Bass
SABINE Existing Design	3.33	3.4	3.45	3.54	3.46	3.38	3.33	3.39	3.43	3.50	0.98	0.97
NOR-ER (E.D.)	2.24	2.31	2.36	2.46	2.38	2.3	2.24	2.30	2.34	2.42	0.96	0.95
MIL-SE (E.D.)	22.76	26.51	21.64	14.63	7.4	4.18	3.35	23.64	24.08	11.02	2.19	2.15
SABINE Proposed Design	3.72	3.81	3.87	4	3.9	3.8	3.73	3.80	3.84	3.95	0.97	0.96
NOR-ER (P.D.)	2.62	2.72	2.77	2.91	2.81	2.7	2.63	2.70	2.75	2.86	0.96	0.95
MIL-SE (P.D.)	21.83	26.69	24.92	18.39	9.46	5.38	4.3	24.48	25.81	13.93	1.85	1.76

***Fig. 3**. Simulation of the open top stadium with and without the new sky boxes*

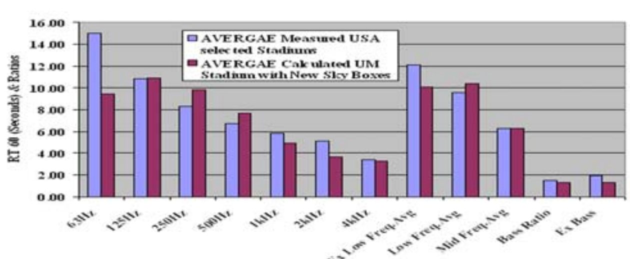

Fig. 4. *Averaged index for well known stadiums compared to simulation results of UM stadium.*

5 CONCLUSIONS

For the biggest football stadiums the reverberation time is one means of determining acceptable acoustics. The UM open-air stadium is compared to enclosed stadiums which often have reverberation times exceeding 10 seconds, which makes speech difficult to understand. Reducing the unwanted sound, the echoes and reverberation requires designers to shape and or treat building surfaces. Hard, smooth objects reflect sound similar to light. Change of surface angles allows the sound to reflect in a desired direction. The new design of the sky boxes allows the reflected sound to be aimed toward the filed, and the glazed wall surface combined with organized crowd noise brings the advantage to the home team. Fiberglass and other porous materials which absorb sound are often used to reduce the sound level. However, the design of partially operable windows allows sky box users finer control over the available sound either reflected by the glass surfaces or absorbed at strategically selected times during the game. NFL football game crowd noise levels range between about 95 to 105dBA with occasional peaks approaching 110 dB. The sound system design must be at least 10 dB louder in order to be understood over that noise. This will be a problem when crowd noise reaches the 115 dBA level that can damage a fan's hearing if exposed for any length of time. Under these conditions it is not permitted for a sound system to produce intelligible sound, and any attempt would put the public at risk. Crowd noise will pose a significant challenge to sound systems. However, the final renovation planned for the UM stadium and its architectural acoustics along with the sound system are well designed, and most fans will be relatively unaware of either as they enjoy the game. Although a sport facility is not the same as a concert hall, the required architectural elements in size and geometry to solve the sound reflections in the low frequency range remain a major challenge in architectural acoustic design, and moreover present a unique demand in recording such effects or the total impact of low frequency sound energy.

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