Study of acoustic performance improvement on Gelora Bung Karno Stadium

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ABSTRACT

Stadion Utama Gelora Bung Karno was the first stadium to be built in Indonesia in 1960. It has the capacity for 88.083 people sitting and 100.800 people standing, making it one of the biggest stadiums in Indonesia. Recent study shows that echoes are clearly perceptible when an impulse sound was excited in the lower tribune of the stadium. This phenomenon is considered disturbing and will affect acoustics comfort of the stadium and impair speech intelligibility as well. This study will analyze the mechanism of the appearance of the echoes and its connection with the geometry that is elliptical, large, and has open space. A simulation of the building has been created using CATT-Acoustic. Furthermore, the proposed design was made based on the echo-disturbance of the stadium.

Keywords: Sports Acoustics, CATT-Acoustic, Echo, Large Space

1. INTRODUCTION

Stadion Utama Gelora Bung Karno is considered as the first and the oldest stadium in Indonesia, built as an elliptical and large geometry with an open space above its field. When first built, this stadium fulfilled the purpose for being the center of football games in Indonesia, as this stadium became the main venue for Asian Games back in the 1962. Being an international level stadium for football games, a good acoustical comfort is expected form the spectator point of view. But a recent study shows that echoes appeared as an impulse sound was generated within the building, leading to a disturbance towards acoustical comforts and impair speech intelligibility. Hence, an improvement design supporting a good acoustical experience is needed for enhancing spectator experience towards watching the game. A good understanding on the behavior of sound in a fully occupied stadium is a mandatory for making the design.

2. METHODOLOGY

2.1 Measurement

Measurement of acoustical property was conducted within the stadium with an impulse response as the main source using sound systems provided by the stadium. Given this situation, some of the acoustical parameters cannot be compared with the one resulted from simulation. Consequently, reverberation time is selected as a comparison. This is based on the reverberation time's trait, as reverberation time does not much be affected by the source position nor the different source characteristics. Figure 1 shows the location of source and receiver used for measurement and simulation. Table 1 shows the results from measurement.

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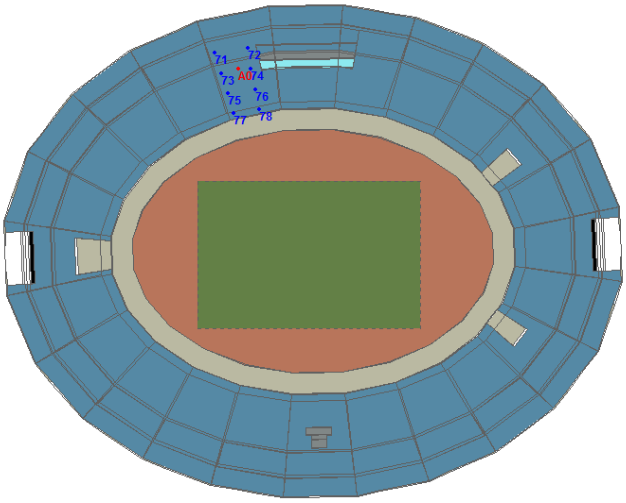

Figure 1 - Position of receivers used in measurement

Table 1 - Measurement results

Position	71	72	73	74	75	76	77	78
Freq (Hz)				EDT				
125	4.606	5.816	5.802	5.926	4.884	4.329	6.226	9.269
250	4.387	3.753	4.843	4.07	4.805	3.922	6.604	5.609
500	4.317	4.888	4.608	4.677	4.559	4.57	6.413	6.171
1000	4.221	4.147	4.392	4.032	3.961	3.834	5.72	6.49
2000	3.606	4.136	3.746	4.063	3.717	3.726	5.056	6.006
4000	2.981	3.903	3.147	3.727	3.138	3.51	4.29	5.283
				T20				
125	5.778	5.11	7.369	5.893	5.955	6.094	6.086	5.959
250	4.645	5.212	4.848	4.813	4.682	4.927	5.29	5.371
500	5.082	5.35	5.332	5.227	5.228	5.217	5.079	5.267
1000	4.764	4.745	4.801	4.734	4.891	4.834	4.652	4.704
2000	4.305	4.284	4.237	4.253	4.263	4.26	4.347	4.598
4000	3.332	3.33	3.387	3.465	3.472	3.374	3.598	3.92
				T30				
125	5.437	4.911	6.722	4.851	5.539	5.747	5.672	4.592
250	4.467	4.972	4.426	4.588	4.413	4.741	4.716	4.976
500	4.78	4.974	4.753	4.844	4.89	4.71	4.559	4.582
1000	4.428	4.576	4.536	4.47	4.533	4.471	4.27	4.23
2000	4.144	4.158	4.061	4.099	4.081	4.11	3.994	4.12
4000	3.397	3.414	3.416	3.432	3.478	3.404	3.479	3.68

2.2 Computer Simulation

Geometry model was first made with SketchUp Make 2015 and exported to CATT-Acoustic software with SU2CATT plugin which result is an acoustic geometry model in CATT-Acoustic as seen on Figure 2. There were simplifications made on the simulation geometry. A triangle-signal shaped ceiling and the steps on tribune was made flat, as well as the steps on tribune, and a scattering coefficient was added to the plane. This simplification occurred to get similar diffusion results of an uneven surface in the existing condition [1]. Simulation was conducted with variations of source's type and position, as listed in Table 2. The position of the sources and receivers are shown in Figure 2.

Table 2 – Sources that are used in the simulation

	Source type	Directivity	Position
A0	White noise	Omni-directional	Lower tribune, near y-axis
A1	White noise	Omni-directional	Curve
A3	Human voice	Human voice	Lower tribune,near y-axis
D0	Human voice	Human voice	Lower tribune, near x-axis
D1	Human voice	Human voice	Lower tribune, near y-axis

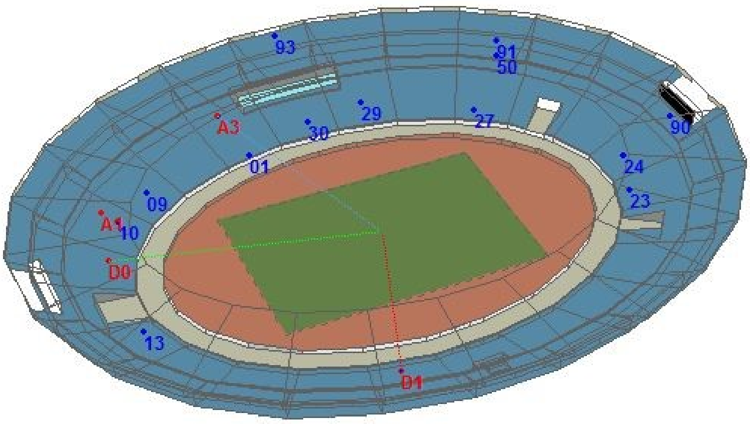

Figure 2 – Position of sources and receivers

2.3 Error Calculation

The difference between the simulation and the measurement was calculated using formula below [2], which results can be seen from Table 3.

$$Error = \frac{\sum \frac{|AP_{measured} - AP_{simulated}| \times 100}{AP_{measured} \times SL}}{N_{Pos}} \quad (1)$$

$AP_{measured}$ = Measured value of the current acoustic parameter

$AP_{simulated}$ = Simulated value of the current acoustic parameter

SL = The subjective limen fot the current acoustic parameter

N_{pos} = Number of measuring positions

The value of subjective limen for RT and EDT is 5%.

Table 3 – Error calculation results in units of subjective limens

Position	Frequency					
	125	250	500	1000	2000	4000
71	4.57	6.6	2.01	1.12	1.72	11.88
72	6.15	4.74	0.74	0.81	7.25	12.44
73	2.62	3.18	1.95	3.55	6.75	12.1
74	6.92	2.58	2.41	4.88	8.29	12.13
75	3.65	4.65	1.88	2.88	5.05	10.91
76	1.51	1.47	1.19	0.14	4.57	10.19
77	2.71	3.58	2.48	0.57	4.47	9.4
78	8.09	2.91	1.39	0.43	4.9	10

This simulation has an overall average error of 4.72 subjective limens.

3. ANALYSIS

3.1 Troublesome Sound Reflections

To analyze the acoustical characteristics of the stadium, variations of simulation was conducted and the results of echo-disturbance, D-50, and T-30 were compared. Scenario used for simulation are from source A0 and A1when the stadium is vacant and fully occupied. While these values are being observed, there are some conclusions that can be obtained. First, the D-50 tends to decrease with increasing distance. While the echo-disturbance of one source and one receiver cannot be generalized with distance. While comparing between vacant and fully occupied stadium gives another conclusion. The D-50 tends to rise as the absorption is raised. While some particular echo-disturbance can be increased or decreased, depending on the reflection path from the source to the receiver. Disturbance from reflections that hit the seats, are decreased while disturbance from reflections that are not hitting the sears, will tends to increase. This is caused by the level difference from the troublesome reflections and the other reflections is increased.

From the variety of simulation above, mechanism of the echo causing a disturbance towards spectator was discovered using image source model from the vacant stadium. The receivers that is getting a disturbance from the echoes was determined using echo-disturbance, then a comparison between the echogram in image source model and echo-disturbance diagram was made to find the cause of the reflection. Using image source model has its own boundary; image source model can only describe the propagation of specular reflections. Thus, to analyze the propagation of a diffuse reflection, comparison between vacant stadium and fully occupied stadium was made. If the results of the echogram from the fully occupied stadiums on the same receiver as the vacant one were declining, then it can be concluded that the sound was reflected at least once at the spectator's seat. This is because if a sound reached the seat on a fully occupied stadium, the energy will be absorbed by the spectator, hence resulting in declining echograms. Another example of a diffuse reflection is from receiver 21 with A4 source. The propagation path of this diffuse reflection is obtained by analyzing the image source model. There were no reflection path with the exact time as the one from echo-disturbance; therefore it is assumed that there are the same propagation paths as the one from image source model with a diffuse reflection. Table 4 & 5 lists the mechanism of echoes that disturbs the spectator from the A0 source. The echo that are considered disturbing are those with echo-disturbance greater than 0.9EK.

Table 4 – Mechanism of echoes that exceed 0.9 EK from A0

Receiver	Time	Cause	Reflection
1	115	Combination of trench's wall and seats	Diffuse
7	25.65	Combination of rear wall, seats, and side wall of VIP box	Diffuse
18	100	Combination of rear wall and field	Specular
21	85	Rear wall	Specular

Table 5 – Mechanism of echoes that exceed 0.9 EK from A1

Receiver	Time	Cause	Reflection
9	40.08	Seats	Diffuse
	66	Ceiling	Specular
10	25.25	Seats	Diffuse
	99.4	Ceiling	Specular
	128	Trench's wall	Specular
21	96	Combination of rear wall and field	Diffuse
	116	Combination of seats, rear wall, and fields	Specular
	145	Combination of trench's wall	Specular

3.2 Acoustic Improvement Area Determination

A simulation with fully occupied seats with a source of human voice was used to represent the existing condition of a football games in the stadiums. The results of this simulation are then used as a base for determining the optimum area for acoustic improvement. Using the same method in determining echoes mechanism, the areas needing an acoustic improvement are achieved and listed in Table 6. The source used is A3 for table 6 and A4 for table 7.

Table 6 – Troublesome echoes mechanism from A0

Receiver	Time (ms)	Echo Disturbance						
		Cause	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
1	53	Trench wall	x		x	x	x	x
	70	Ceiling	x	x	x	x	x	x
	83	Ceiling	x	x	x	x	x	x
9	40	Ceiling			x	x	x	
	45	Ceiling				x	x	
30	51.5	Ceiling	x	x	x	x	x	x
50	25.5	Ceiling				x		

Table 7 – Troublesome echoes mechanism from A1

Receiver	Time (ms)	Echo Disturbance						
		Cause	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
1	37.47	Ceiling				x	x	
9	70	Ceiling	x	x	x	x	x	x
10	98.2	Ceiling	x	x	x	x	x	x
13	33	Ceiling				x	x	x
23	114	Trench wall	x	x	x	x	x	x

Table that are marked (x) indicates that the value of echo-disturbance in those receivers were above 0.9. From these results, the areas that are to be acoustically improved are determined. For source A3 and receiver 01, there are disturbances coming from the trench wall on 53ms and one coming from the ceilings on 70ms. Assuming that the stadiums are fully occupied, there will be another source coming from the spectator and receiver that is also the spectator which has the exact same positions as A0 and 01 are. In conclusion, the disturbances coming from ceilings and trench wall will always occur in this stadium. Therefore, an acoustic improvement will be made on the ceilings and trench wall.

4. ACOUSTIC PERFORMANCE IMPROVEMENT

4.1 Acoustic Treatments

To degrade the level of disturbance on a receiver, the sound level of the reflection must be reduced. This can be achieved by using an absorber or a highly absorptive material on the area needing an improvement. Acoustic Improvement on the ceiling was made by adding an acoustic deck in it. The absorption coefficient of the acoustic deck used is listed on Table 8

Table 8 – Absorption coefficient of the material used on the ceiling

Absorption Coefficient					
125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
0.48	0.56	0.98	0.92	0.72	0.58

The improvement on the trench wall was chosen to be sustainable on the outdoor venue as Stadion Utama Gelora Bung Karno is opened stadium. Table 9 shows the absorption coefficient of the absorber used on the trench wall.

Table 9 – Absorption coefficient of the material used on the trench wall

Absorption Coefficient					
125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
0.22	0.77	0.99	0.99	0.78	0.57

4.2 Results

Table 10 – Comparison of maximum EK value before and after design from D0

Freq (Hz)	Echo-disturbance max (EK)											
	24		27		29		90		91		93	
	before	after	before	after	before	after	before	after	before	after	before	after
125	0.85	0.68	0.89	0.72	0.68	0.53	0.67	0.73	0.56	0.62	0.5	0.57
250	0.92	0.73	0.87	0.63	0.56	0.52	0.61	0.58	0.69	0.79	0.56	0.45
500	0.83	0.7	0.92	0.77	0.61	0.56	0.66	0.71	0.54	0.59	0.48	0.53
1000	0.92	0.63	1.04	0.78	0.61	0.48	0.78	0.79	0.61	0.51	0.5	0.42
2000	0.85	0.63	0.98	0.65	0.61	0.53	0.75	0.63	0.67	0.46	0.48	0.42
4000	0.81	0.78	0.9	0.61	0.56	0.66	0.68	0.57	0.53	0.44	0.45	0.42

Table 11 – Comparison of D-50 value before and after design from D1

Freq (Hz)	D-50											
	24		27		29		90		91		93	
	before	after	before	after	before	after	before	after	before	after	before	after
125	34.18	54.93	50.66	66.32	58.47	75.68	32.9	50.5	44.11	64.16	56.8	75.91
250	39.62	66.75	62.3	71.26	67.92	81.3	47.09	63.93	47.65	71.31	63.82	85.77
500	68.23	94.29	77.57	86.24	86.12	96.99	65.48	80.53	78.91	96.73	88.02	98.45
1000	70.59	97.01	82.63	87.25	90.82	98.21	67.16	76.32	86.42	98.37	93.89	99.01
2000	74.44	94.19	83.18	86.85	90	95.61	72.47	79.55	85.27	95.79	92.58	97.69
4000	79.56	90.06	87.95	89.11	92.41	92.51	77.13	82.62	89.61	94.09	93.91	96.3

Table 10 shows the comparison of maximum echo-disturbance value between the results after improvement and before improvement, whereas table 11 shows the comparison of D-50 between after and before improvement as well. The source used is D0.

5. CONCLUSIONS

Computer simulation of Stadion Utama Gelora Bung Karno shows that the D-50 in Stadion Utama Gelora Bung Karno tends to decrease when the distance between the source and the receiver is raised. The echo-disturbance of this stadium is difficult be generalized when the distance or the absorption is changed. Adding absorption can cause the energy of the troublesome echo to be decreased while can raise the difference between the troublesome echo and the rest of the echoes, causing higher echo-disturbance. This finding becomes the base to design the acoustic improvement.

Absorptive materials were added to the acoustic model in the computer simulation in the ceilings and the trench walls. The results shows that the maximum value of the echo-disturbance tends to decline while the D-50 tends to rise.

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