A STUDY OF THE SIMULATION OF THE VISIBILITY OF BASEBALLS FLYING IN THE DOME STADIUM

Mitsuru Saito[*1], Hiroshi Nakamura[*2], Tetsuji Tanaka[*3], Kouji Kawakami[*3]
*1 Obayashi Corporation,2-15-2 Konan,Minato-ku,Tokyo108-8502,Japan
*2 Kouchi Prefectural Women's University,15-5 Eikokuji-cho,Kochi,780-8515,Japan
*3 Iwasaki Electric Co.,Ltd.,3-12-4 Shiba,Minato-ku,Tokyo105-0014,Japan

ABSTRACT

An evaluation system of the visibility of a ball flying is indispensable for the best architectural design and artificial lighting design of a baseball dome stadium, as it is essential to create a suitable visual environment for both players and spectators to watch the ball.

This paper describes a simulation theory of the visibility of balls flying in the baseball dome space proposed by the authors and shows the recommendable reflectance of the construction material and suitable artificial lighting system by the simulated results of a model dome stadium. The results of this research work convinced the authors of its contribution to construct the visually comfortable environment of a dome interiors.

INTRODUCTION

Five baseball dome stadiums, those are Tokyo Dome, Fukuoka Dome, Osaka Dome, Nagoya Dome and Seibu Dome have been completed in Japan. Tokyo Dome is the only membrane structure dome in Japan. Its roof is covered with diffuse translucent membrane. Also Fukuoka Dome is the only rigid-structure type with the retractable roof. These domes are multi-purpose stadiums, suitable for a wide range of sports as well as for concerts and trade-shows, etc.. The official games of the professional baseball as one of the sporting events have being held in those stadiums. The best visual environment is required for these games , because a ball which players and spectators watch is very small and moves at high speed. For this reason, the evaluation of the visibility of a ball flying in the baseball dome space is very important for the best architectural design and artificial lighting design.

The visibility of an object can be judged by the contrast of the luminance of an object surface and its background. Accordingly we can do a simulation of the visibility of a ball flying in the baseball dome space by calculating the luminance of a ball surface and its background.

CALCULATION METHOD OF THE LUMINANCE OF A BALL AND ITS BACKGROUND

The finishing of a ball and all inner surfaces of the dome is assumed to be diffusive. If we know the illuminance of a ball surface and its background, the luminance can be calculated as shown below.

$$L_T = \frac{\rho_T \cdot E_T}{\pi} \quad \cdots\cdots\cdots (1)$$

$$L_B = \frac{\rho_B \cdot E_B}{\pi} \quad \cdots\cdots\cdots (2)$$

L_T : Luminance of a ball surface [cd/m²]
L_B : Luminance of background [cd/m²]
E_T : Illuminance of a ball surface [lx]
E_B : Illuminance of background [lx]
ρ_T : Reflectance of a ball surface [-]
ρ_B : Reflectance of background [-]

ILLUMINANCE OF A BALL

It is convenient to calculate the semi-spherical illuminance of a ball surface, because players and spectators can only watch the half surface of a ball. The semi-spherical illuminance is defined as the incident flux density per the perceivable hemi- sphere area of a ball. Semi-spherical illuminance of a ball flying can be calculated by the sum of direct illuminance and indirect illuminance.

Fig. 1 shows the relation between direct semi-spherical illuminance and normal illuminance of a ball surface. Direct semi-spherical illuminance by a light source can be calculated by the Eq. (3).

$$E_{hsd} = \sum_{i=1}^{ns} E_i \cdot \frac{1+\cos\gamma_i}{4} \cdots\cdots (3)$$

E_{hsd} : Direct semi-spherical illuminance of a ball surface [lx]
E_i : Normal illuminance of a ball surface by a light source i [lx]
n_s : Number of light sources [-]
γ_i : Angle between the normal line of the orthogonal bottom face of a semi-sphere to the observer's sight line and the line which connects the center of a semi-sphere to a light source i [rad.]

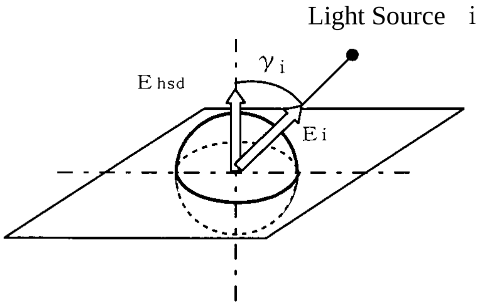

Fig.1 Direct semi-spherical illuminance by a light source

The Eq. (4) as shown below, proposed by Haeger, F[1] is applicable to calculate the indirect semi-spherical illuminance by interreflection in an interior of a dome.

$$E_{hsi} \fallingdotseq E_{4\pi} + \frac{E_0}{4} \cdots\cdots (4)$$

E_{hsi} : Indirect semi-spherical illuminance of a ball surface [lx]

$E_{4\pi}$: Average spherical illuminance of a ball surface (scalar illuminance) [lx]

$$E_{4\pi} \fallingdotseq \frac{\sum E_j}{6}$$

E_j : Six-elements illuminance [lx]

j : 1 ～ 6 (see Fig. 2)

E_0 : Difference between the illuminance on the calculation plane of semi-spherical illuminance and the opposite plane [lx]

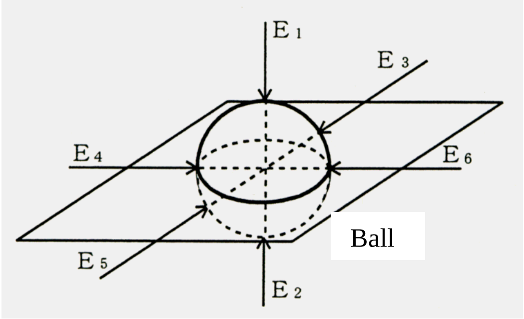

Fig.2 Six-elements illuminance of a ball surface

E_1, E_2 :Horizontal illuminance on the two planes

E_3～E_6 :Vertical illuminance on the four planes

ILLUMINANCE OF BACKGROUND

A ball hit by a batter flies under the ceiling of the dome. Consequently we can know the illuminance of background by the Eq. (5) for the calculation of the illuminance at a arbitrary point of the ceiling of a dome. The illuminance of the ceiling of a dome can be calculated by the sum of direct illuminance and indirect illuminance like the calculation of the semi-spherical illuminance.The average illuminance of the ceiling is obtained by the ʻFour Points Methodʼ of the average illuminance calculation method using the illuminance at many arbitrary points.

$$E_{vi} = E_{vid} + E_{vii} \cdots\cdots (5)$$

E_{vi} : Illuminance at a arbitrary point of ceiling [lx]

E_{vid} : Direct illuminance at a arbitrary point of ceiling by light sources [lx]

E_{vii} : Illuminance at a arbitrary point of ceiling by the floor (ground) [lx]

$$E_{vii} = \rho_{fg} \cdot E_{fg} \cdot U_{ig} \quad \cdots (6)$$

ρ_{fg} : Reflectance of floor [-]

E_{fg} : Average illuminance of floor [lx]

U_{ig} : Configuration factor of floor to a arbitrary point of ceiling [-]

THRESHOLD OF THE CONTRAST OF THE LUMINANCE FOR GOOD VISIBILITY OF A BALL FLYING

The visibility of a ball is affected by the contrast of the luminance of the ball surface and its background . The threshold of the contrast of the luminance for good visibility of a ball was investigated by an experiment carried out in a dome covered with diffuse translucent membrane2) . In this experiment the contrast of the luminance was defined as the Eq. (7) .

$$C = \begin{cases} \dfrac{L_T - L_B}{L_T} & (\text{for } L_T \geqq L_B) \\ -\dfrac{L_B - L_T}{L_B} & (\text{for } L_B > L_T) \end{cases} \cdots\cdots (7)$$

C : Contrast of the luminance of the ball surface and its background [-]

L_T : Luminance of a ball surface [cd/m²]

L_B : Luminance of background [cd/m²]

When the luminance L_T of the ball surface is greater than the luminance L_B of its background, it is called as ʻPositive contrastʼ. In the case that L_T is less than L_B, it is called as ʻNegative contrastʼ. The obtained results of the threshold of the contrast of the luminance for good visibility by this experiment were 0.3 for positive contrast and -0.4 for negative contrast.

ILLUMINANCE BOUNDARY CONDITIONS FOR GOOD VISIBILITY

The level of the visibility of a ball flying in a dome space is predicted by the calculation of the illuminance boundary conditions for visibility. The illuminance boundary conditions for good visibility can be calculated by the threshold of the contrast of the luminance mentioned before as follows.

Good visibility of a ball flying can be taken by satisfying the next condition for positive contrast.

$$\frac{L_T - L_B}{L_T} \geqq 0.3 \quad \cdots\cdot(8)$$

$$\therefore \quad L_T \geqq \frac{L_B}{0.7} \quad \cdots\cdot(9)$$

The Eq. (10) is obtained by inserting the Eq. (1) and Eq. (2) to the Eq. (9).

$$E_T \geqq \frac{\rho_B \cdot E_B}{0.7 \cdot \rho_T} \quad \cdots\cdot(10)$$

For negative contrast, the illuminance condition for good visibility can be taken by the same way.

$$-\frac{L_B - L_T}{L_B} \geqq -0.4 \quad \cdots\cdot(11)$$

$$\therefore \quad L_T \leqq 0.6 \cdot L_B \quad \cdots\cdot(12)$$

$$E_T \leqq \frac{0.6 \cdot \rho_B \cdot E_B}{\rho_T} \quad \cdots\cdot(13)$$

Accordingly if the illuminance of a ball flying in a dome space is within the limit of Eq. (14), the visibility of a ball is not good. The Eq. (14) shows the illuminance boundary condition for the visibility of a ball.

$$\frac{0.6 \cdot \rho_B \cdot E_B}{\rho_T} < E_T < \frac{\rho_B \cdot E_B}{0.7 \cdot \rho_T} \quad \cdot\cdot(14)$$

The visibility of a ball is influenced by E_T, E_B, ρ_T, ρ_B and can be simulated by using the Eq. (14). Also the ball illuminance is affected by the reflectance of the construction material and artificial lighting system.

SIMULATION EXAMPLES

The visibility of a ball flying in a model dome space were simulated for six kinds of artificial lighting system and three kinds of the reflectance of construction material of the ceiling.

Fig. 3 and Fig. 4 show the plan and section of a model dome stadium. The distance from home-base to the widest point of outfield is 122 m. The height under the dome is 70 m. The reflectances of inner surface of a dome and ball surface are as follows.

Ceiling : 80%, 50%, 30%

Wall : 10%

Artificial turf : 15%

Ball : 75%

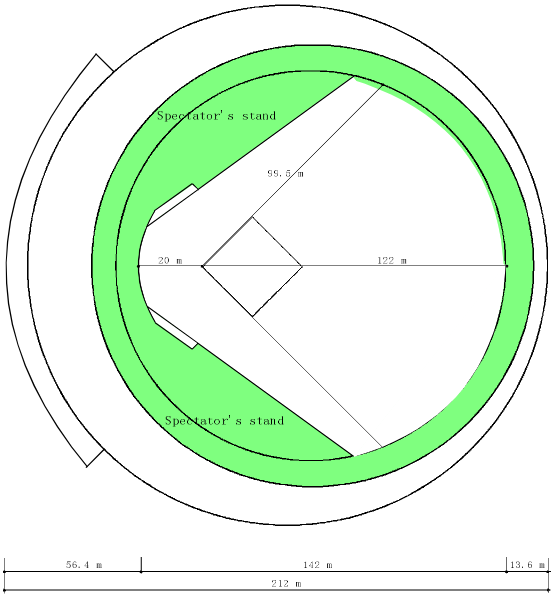

Fig.3 Plan of a model dome stadium

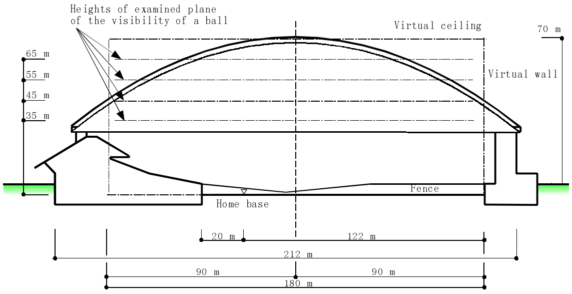

Fig.4 Section of a model dome stadium

For the official game of the professional baseball, a number of stringent lighting criteria were laid down. These related not only to the suitable visual environment for the players and spectators, but also to the TV cameras for broadcasting. The level of horizontal illuminance is one of the most critical of these criteria. The maintained illuminance of 2500 lux by artificial lighting is provided for the playing zone of battery. Also, its illuminance for infield zone and outfield zone are 2000 lux and 1500 lux. Maintenance factor of artificial lighting is 0.69.

The six kinds of artificial lighting system were considered for the simulation of the visibility of a ball flying in a model dome space. Table 1 shows the list of the luminaires used for the each lighting system. The specification of each luminaires in the Table 1 is as follows.

A : Floodlight with 1 kW metal halide lamp of the narrow-beam,rotationally symmetrical type
B : Floodlight with 1 kW metal halide lamp of the medium-beam,rotationally symmetrical type
C : Floodlight with 1 kW metal halide lamp and hood-louver,rotationally symmetrical type

Table 1 List of the Luminaires

System No	Artificial lighting Equipments					
	Floodlights for the lighting of playing-field area		Floodlights for the lighting of upper zone space		Floodlights for the lighting of playing-field area hung at batons	
	Luminaire	No. of floodlights	Luminaire	No. of floodlights	Luminaire	No. of floodlights
1	A	528	—	—	—	—
	B	432				
2	A	528	C	56	—	—
	B	432				
3	A	224	—	—	—	—
	D	736				
4	A	224	—	—	—	—
	E	926				
5	A	224	F	112	—	—
	E	930				
6	A	240	—	—	E	400
	D	360				

D : Floodlight with 1 kW metal halide lamp of the wide-beam, rectangularly shaped type
E : Floodlight with 1 kW metal halide lamp and hood-louver,rectangularly shaped type
F : Floodlight with 2 kW metal halide lamp and louver, rectangularly shaped type

The lamp flux of metal halide lamp is 115000 lm for 1 kW and 185000 lm for 2 kW. The luminaires except floodlight E are installed on the wall at 34 m height above the ground level. The luminaire E is installed on the ceiling at 50 m height above the ground level.

The simulation points of the visibility of a ball were selected at the arena area in a dome. The heights of examined plane of the visibility are 35m, 45m, 55m and 65m above the ground level. Fig. 5 shows the all of the simulation points. Five watching directions of a ball were considered.

SIMULATED RESULTS

Table 2 shows the calculated average and standard deviation of the illuminance of ceiling. The illuminance distribution of ceiling was assumed as the normal distribution. The illuminance E_B of background in the Eq. (14) was assumed as the sum of the average and standard deviation for positive contrast, and the difference between the average and standard deviation for negative contrast. The semi-spherical illuminance for not good visibility of a ball calculated by the Eq. (14) is also shown in Table 2. If the semi-spherical illuminance of a ball flying is within the E, we can judge that the visibility of a ball is not good.

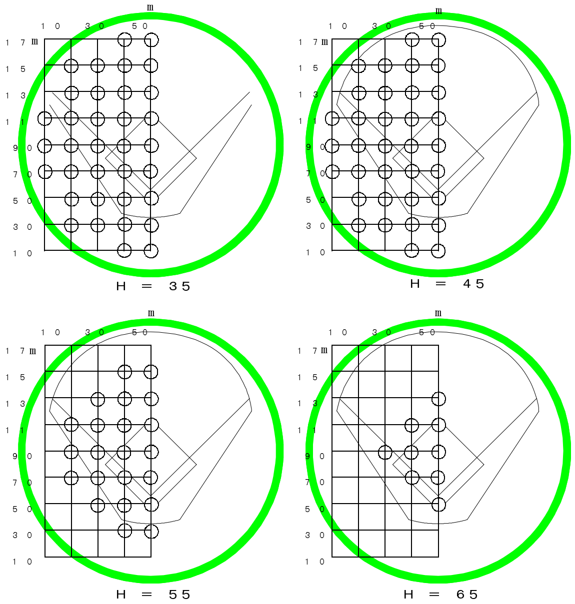

Fig.5 Simulation points of the visibility of a ball
(H : Height above the ground level)

Table 2 Calculated results of the illuminance of ceiling and semi-spherical illuminance for not good visibility of a ball

System No	Average and standard deviation of the illuminance of ceiling [lx]		Reflectance of ceiling [%]	Semi-spherical illuminance E for not good visibility of a ball [lx]
	Ave. illuminance	Standard deviation		
1	286	57	80	$147<E<523$
			50	$92<E<327$
			30	$55<E<196$
2	321	65	80	$164<E<588$
			50	$102<E<368$
			30	$61<E<221$
3	294	60	80	$150<E<539$
			50	$94<E<337$
			30	$56<E<202$
4	247	42	80	$131<E<440$
			50	$82<E<275$
			30	$49<E<165$
5	333	56	80	$177<E<593$
			50	$111<E<370$
			30	$66<E<222$
6	270	44	80	$145<E<478$
			50	$90<E<299$
			30	$54<E<179$

Fig. 6 shows one of the simulated results of the visibility. The numerical value in each box of Fig. 6 shows the semi-spherical illuminance of a ball and shadowed boxes indicate that the visibility of a ball is not good. Table 3 shows all the estimated results of the visibility of a ball by using the same results of 72 cases as shown in Fig. 6.

Y＼X	10m	30m	50m	70m	90m
170m				366 284 300 218 377	438 363 363 288 459
150m		238 121 262 145 251	398 413 313 328 478	444 464 357 377 517	441 407 407 372 507
130m		357 355 301 299 440	438 487 340 389 526	430 443 365 378 504	416 395 395 373 490
110m	191 100 241 150 227	415 463 313 362 509	440 487 340 388 521	418 432 359 373 492	406 386 386 367 480
90m	208 143 247 181 266	452 504 319 371 536	442 486 340 384 519	416 429 359 372 491	401 383 383 365 477
70m	177 112 232 168 235	466 526 314 374 555	443 496 332 386 524	409 434 351 376 490	403 388 388 373 483
50m		402 487 276 361 528	425 511 302 388 524	396 448 337 389 493	389 388 388 387 484
30m		121 124 192 194 218	320 436 240 356 456	300 411 262 373 431	271 317 317 363 400
10m				79 189 188 257 244	128 202 202 277 258

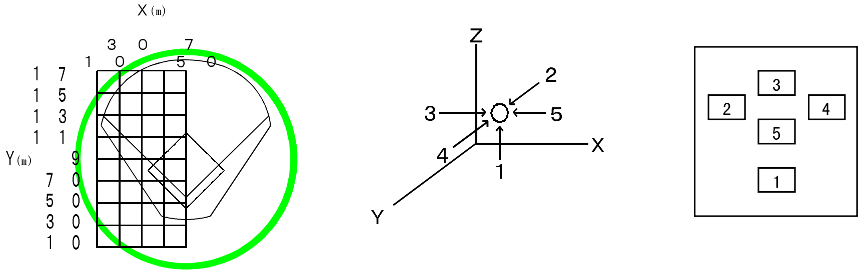

Fig.6 Example of the simulated result of the visibility of a ball
(Lighting system：2, Height of examined plane：45m, Reflectance of ceiling：50%)

Table 3 Estimated results of the visibility of a ball

Reflectance of ceiling [%]	Lighting system	Heights of examined plane of the visibility of a ball above the ground [m]			
		35	45	55	65
80	1	△	×	×	×
	2	○	×	×	×
	3	△	×	×	×
	4	×	△	△	△
	5	△	△	△	△
	6	△	×	×	×
50	1	○	△	△	×
	2	○	○	△	×
	3	○	○	△	×
	4	△	×	×	×
	5	○	○	×	×
	6	○	△	×	×
30	1	◎	◎	○	○
	2	◎	◎	◎	○
	3	◎	◎	○	○
	4	◎	△	△	△
	5	◎	◎	△	△
	6	◎	◎	△	△

◎ : Visibility at all points is good for all watching directions.
○ : Visibility at all points is good for the most watching directions. Best visibility is for the direction from the bottom.
△ : Visibility at many points is not good for many watching directions.
× : Visibility at the most points is not good for all watching directions
.

We can understand that the best visibility of a ball is in the case of lighting system 2 with the 30% of ceiling reflectance from the Table 3.

CONCLUSIONS

The visibility of a ball flying in the baseball dome space is able to be simulated by the calculation of the contrast of the luminance of a ball surface and its background. The simulation is able to contribute to the best architectural design and artificial lighting design of a baseball dome stadium.

We can recommend 30% as the reflectance of ceiling and artificial lighting system with the combination of floodlights for the lighting of playing-field and upper zone space installed on the wall through the simulation. All luminaires are the floodlights with 1 kW metal halide lamp, rotationally symmetrical type.

ACKNOWLEDGMENTS

The experiment for obtaining the threshold of the contrast of the luminance for good visibility of a ball was carried out with the assistance of Dr. Matsuura, Professor Emeritus of Kyoto University and Dr. Uetani of Assistant Professor of Fukuyama University.

REFERENCES

1)Haeger, F. : Uber die Messung von Lichtfeldgroβen zur raumlichen Bewertung der Beleuchtung mit einfachem Me instrumentarium, LICHTTECHNIK, 26, Jahrgang, No.9, pp.385-388(1974)

2)Saito, M., Kashihara, K., Uetani, Y., Matsuura, K., Hori, T. : Experimental Study on the Visibility of a Flying Ball in a Membrane Structure, J. of IEIJ, Vol.79, No.2, pp.78 - 84(1995)