STUDY ON VISIBILLTY OF AFTERGLOW PIGMENT-BASED SIGN FOR OUTDOOR EVACUATION

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SUMMARY:
We authors suggest afterglow phosphorescent signs as a guide to evacuate. It functions during the power failure or outage, does not require energy source, easy to install in an electricity-free environment and its maintenance free. When excitation of phosphorescent paint (200-450nm) stops by power failure, its afterglow luminance decreases exponentially. Due to its unsteady characteristics, the accuracy rates of afterglow visibility evaluation test on phosphorescent signs are not very high. Since afterglow excitation mostly occurs in the ultraviolet region, we developed an experiment method to stabilize the level of afterglow luminance during the elapsed time after a power cut by using a black light. By applying this technique, we examined the luminance level and visual attractiveness of guide signs. These would be the index measurement of afterglow phosphorescent signs and installation intervals.

Keywords: Blackout Visibility of afterglow phosphorescent signboard Outdoor disaster prevention lighting

1. INTRODUCTION

Large-scale earthquake causes power failure over a wide area. In The Great Hanshin-Awaji earthquake, 2.6 million houses, and in The Great East Japan Earthquake in 2011, 8.9 million houses were affected by power failure. When power failure occurs at night, evacuation and rescue operations can be extremely difficult. However, the effect of a wide area lengthy hour electrical power failure during evacuation and rescue operation has not been assumed in current disaster prevention plan. Therefore, there is no legal obligation for disaster prevention lighting equipment such as emergency lightings, guidance and signs. In the case of the great ocean trench type earthquakes and major earthquakes in the metropolitan area, to establish outdoor evacuation guiding system is one of the urgent priorities.
We authors suggest afterglow phosphorescent signs as a guide to evacuate. It functions during the

power failure or outage, does not require energy source, easy to install in an electricity-free environment and its maintenance free. We conducted a walking experiment in total dark situation with sample afterglow phosphorescent signs and gateway lights. Both function in a power outage situation. The result of our experiment proves that the afterglow phosphorescent signs are effective for evacuation. Even if levels of luminance are low on the surface, as long as they are installed with appropriate spacing, they can be effective in the wide-area power failure situation where background luminance level is low. When excitation of phosphorescent pigment (200-450nm) stops by power failure, its afterglow luminance decreases exponentially. Due to its unsteady characteristics, the accuracy rates of afterglow visibility evaluation test on phosphorescent signs are not very high. Since afterglow excitation mostly occurs in the ultraviolet region, we developed an experiment method to stabilize the level of afterglow luminance during the elapsed time after a power cut by using a black light. By applying this technique, we examined the luminance level and visual attractiveness of guide signs. These would be the index measurement of afterglow phosphorescent signs and installation intervals.

2. SECURING BRIGHTNESS AND ABILITY TO GUIDE

2.2 Securing brightness

The lightings in the escape route required to have enough luminance to determine and avoid obstacles during evacuation. The luminance of the escape route is considered to have effects on walking speed of evacuees. Therefore, horizontal luminance of roads in relation to walking speed and psychological states of evacuees have been subjects of discussion. Most of these studies are purposed for home fire evacuation. The Disaster Prevention Lighting Committee(1997) at Kansai branch of the Illuminating Engineering Institute of Japan (IEIJ) has performed an evacuation experiment on a simulation street where obstacles are laid out. In this experiment, the following points are considered by the use of obstacle size, luminance ratio of obstacle and road surface luminance as parameters.

- Consideration of distinctive minimum distance of an obstacle
- Consideration of necessary walking time to avoid obstacles
- Subjective evaluation to see whether luminance is enough for safe walking

As a result, 0.1～0.3lx illuminance is required on the basis of visibility and illuminance of 0.3 lx is required psychologically. From these studies, it is clear that illuminance of 1.0lx which is a required brightness for evacuation for indoor fire is not necessary for outdoor evacuation.

2.2 Ability to guide

To enable a smooth evacuation, lighting equipments and guide signs to indicate direction are essential. To install emergency lighting equipments and indicate emergency exits and its direction in buildings are prescribed in the Fire Defense Law. An essential ability for emergency lighting is that it can be seen from a distance. It must have clear visibility and must not be affected by high luminance sources of the background lightings.

Visual attractiveness and visibility of signs depends on their luminance and size of the display. As for emergency lighting, size and surface luminance are known to be related. Those in formations are purposed to secure evacuation at the time of the fire. Whether the in formations on visibility and visual attractiveness for fire evacuation can be adapted to the situations of wide area electrical power failure, require close examinations.

3. EVALUATION OF SAMPLE AFTERGLOW PHOSPHORESCENT SIGNS IN NIGHT, NO-LIGHT ENVIRONMENT

3.1 Experiment outline

3.1.1 Afterglow phosphorescent guide signs

Evaluation test was conducted after the moonset from 21:00 to 24:00, December 03, 2007 at a straight-running truck in a provincial town, in the mountain region. There were almost none outdoor lightings in the surrounding area.

We prepared two types of vertical 30cm× Horizontal 42cm afterglow phosphorescent signs(**Figure 1** Guide sign type A, **Figure 2** Guide sign type B). Signs were displayed in approximately 1m (1050mm) center height on the side street in opposite to subjects.

Figure 1. Guide sign type A

Figure 2. Guide sign type B

The afterglow phosphorescent material was D65 standard light source, in color 523nm. It can provide luminescence of 200lx for 20minutes. The reflection measurements on mat black paper we used on guide sign were 0.06.

After excitation in a room with floor illuminance level of 800lx or above. Within 5 to 25 minutes after the excitation, we conducted the evaluation test. The estimated fall of afterglow luminance during this period of time is from 0.63cd/m^2 to 0.09 cd/m^2. Due to the cloudy weather on that day, sky luminance level fluctuated from 0.04lx to 0.01lx. Luminance level (cd/m2) during 3 - 60 minutes can be measured by using equation (1)

$$L=3.65T^{-1.095} \cdots \cdots (1)$$

After that, calculate from elapsed time T (minutes).

3.1.2 Emergency lighting

For the emergency lighting, we used 10cm cubic emergency gateway lamp (in white acrylic cover) with white LED light of 6V, DC (3.3w during power failure). We displayed lightings at approximately 1200mm high (center height 1252mm) assuming as gateway light.

3.2 Evaluation Method

Both afterglow phosphorescent signs and gateway lights were installed at intervals of 10m, 20m, 30m, 40, and 50m. Test subjects were measured their walking speed for 50m and asked to evaluate the ability to guide in 7 levels. In addition, we asked for the preference of positive contrast or negative contrast of afterglow phosphorescent signs. The comparison of emergency lighting and afterglow phosphorescent signs were non-installed environment.

Test subjects were 13 youth (mean age: 21.2 years, mean corrected visual acuity: 1.2) and 4 matured (mean age: 50.1 years, mean corrected visual acuity: 1.0). All subjects are eyesight of 0.8 and above, and none of the subjects had problems in color sense. Despite our consideration that the walking speed, height, age, and vision are in relation to the walking speed in a no-light situation, we found no significant correlation. In this experiment, physical attributes did not have any affects on walking speed.

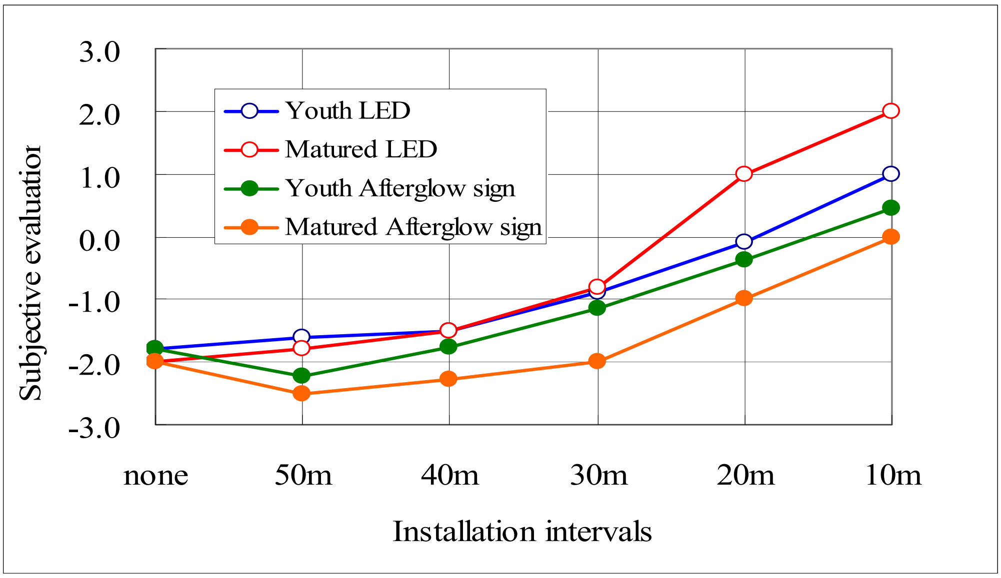
3.3 Decrease in afterglow luminance and contrast

As for the evaluation of the background of guide signs and positive and negative contrast of the pictogram, 100% of matured group and 76.9% of youth group preferred Type A guide sign. Since the light emitting area of Type A guide signs were larger, subjects found Type A afterglow phosphorescent signs easier to recognize. This is the basis of their evaluation. Afterglow phosphorescent signs we adopted in this experiment consisted of afterglow phosphorescent material and low reflection black. This may lower the afterglow luminance but the luminance ratios remain unchanged. In the situation of power failure, background luminance level approaches to almost 0 and afterglow phosphorescent signs remain recognizable even though their luminance level is low. Use of other luminance sources such as a flashlight during the evacuation may lower the visibility of afterglow phosphorescent signs. Further studies on size and content of the guide sign may be necessary.

The luminaries applied to emergency lighting were effective luminance source as light intensity covers surrounding area of 5m in luminance level of 0.05lx or above. In urban areas, dwelling units are spaced out in the interval of 10 meters or less. In that situation, this emergency lighting may be useful.

3.4 Evaluation on the relation of sign installation spacing and its walk ability and ability to guide

Subjective assessments on afterglow luminance and walk ability and ability to guide are shown in **Figure 3** According to the result, subjects evaluated afterglow phosphorescent signs as "Bad" when their intervals exceeded 10m for matured group and 20m for youth group. On the other hand, both groups evaluated emergency lighting as "Bad" when the intervals exceeded 20m.



Subjective Evaluation：3: Very Good, 2: Good, 1: Slightly Better, 0:Neither, -1: Slightly Bad, -2: Bad, -3: Very Bad

Figure 3. Subjective assessments on afterglow luminance and walk ability and ability to guide

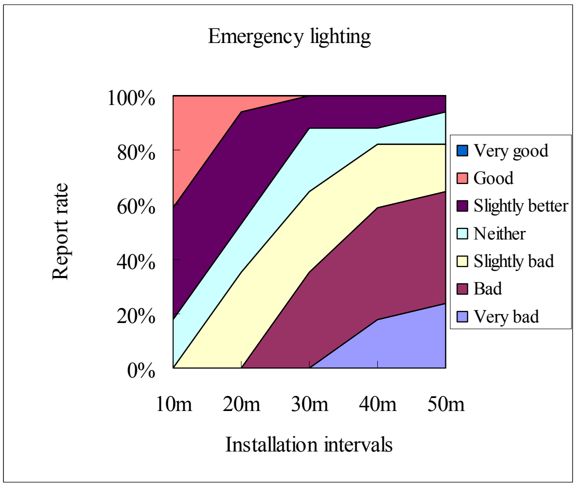


Figure 4. Subjective evaluation result of emergency lightings

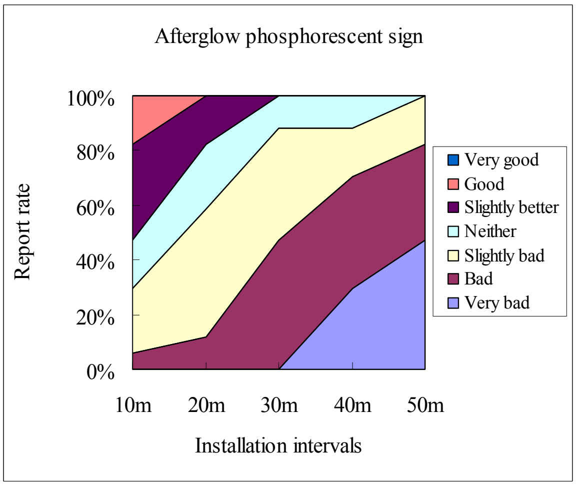


Figure 5. Subjective evaluation result of afterglow phosphorescent signs

Subjective evaluation result of emergency lightings and installation interval is shown in **Figure 4. Figure 5** is the subjective evaluation result of afterglow phosphorescent signs and installation intervals. These diagrams indicate the relation between report rate on subjective evaluation (Indicating % of evaluation) and installation intervals. Emergency lightings were rated "Good" in up to 20m intervals. "Good" remark disappears after 30m onwards, though "Slightly Better" appears even in 50m installation intervals. This expresses the importance of outdoor lighting equipment in an emergency situation. Afterglow phosphorescent guide signs were evaluated as "Slightly Better" in 10m installation interval. "Good" disappears from 30m onwards and in 50m, most subjects marked them as “Slightly Bad " or worse. This may be due to the fact that the background luminance in this experiment was not 0. The levels of afterglow luminance were lowered, and visibility of signs fell in accordance.

4. EVALUATION OF SIZE AND SPACING INTERVARLS OF AFTERGLOW PHOSPHORESCENT SIGNS

4.1 Experiment outline

Since afterglow excitation mostly occurs in the ultraviolet region, we developed an experiment method to stabilize the afterglow luminance after elapsed time by using black light. By applying this technique, we examined the luminance level and visual attractiveness of guide signs, which would be the index measurement of afterglow phosphorescent signs and installation interval.

The relation of afterglow luminance and its elapsed time for the afterglow phosphorescent material (product name: LumiNova) are calculated in equation (2)

$$L=2.8264T^{-1.1455} \cdots\cdots\cdots\cdots\cdots \quad (2)$$

L: Afterglow luminance [cd/m^2]   T: Elapsed Time [minutes]

This calculation explains that in the situation of power failure, the level of luminance of afterglow phosphorescent material excited by light drops to 0.101cd/m^2 after 20 minutes, and 0.03cd/m^2 after 60minutes.

In this experimental situation of emergency, subjects are to evacuate to safety shelter in complete dark environment after the power cut. In order to adapt to this situation, subjects remained in dark for 10 minutes before starting the experiment.

Conditions to compare are the “Equal Brightness" and “Equal Markedness" of two signs in different luminance level. Subjects were asked to compare two square-sized afterglow phosphorescent materials. Experimenter gradually reduces the size of the afterglow phosphorescent materials until subjects say "The brightness of two squares are equal". Same method was applied to measure "Markedness".

4.2 Relation between luminance and size of signs according to their visual attractiveness

Consider the relation between luminance level of index afterglow phosphorescent signs and their sizes in order to verify the index luminance and viewing angle. Also, verify how human receives light by considering the relation between “Total luminance amount received from surface" and "Markedness".

4.2.1 Experiment Method

Measured visual attractiveness of afterglow phosphorescent signs by applying equipment below in **Figure 6** After 10 minutes of darkness, subjects (N=14, mean age: 23.1 years) were presented three different patterns of indicators. Luminescence was maintained at the level of 30－100 mcd/m^2, 100－300 mcd/m^2 and 300－1000 mcd/m^2, right to left. By altering the frame of high luminance index, we calculated the size measurement to match the brightness and markedness (visual attractiveness) of signs with low luminance.

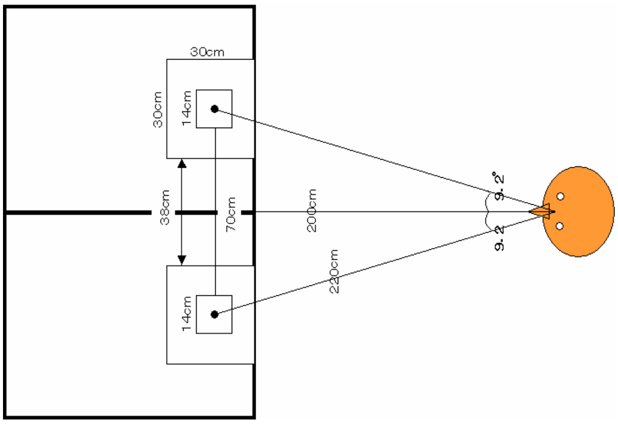


Figure 6. Measured visual attractiveness of afterglow phosphorescent signs by applying equipment

4.2.2 Experiment results and discussion

As shown in **Figure 7.** and **8.**, In Comparison Pattern 1, a sign with luminance level of 30mcd/m^2 in size 195cm^2 has equal brightness to luminance level 100mcd/m^2 in size of 64.3cm^2 (33% of 195cm^2) and the area of equal markedness was 58.7cm^2(30%). In Comparison Pattern 2, a sign with luminance level of 100mcd/m^2 in size of 195cm2 has equal brightness to luminance level 300mcd/m^2 in size of 50.3cm^2(26%) and the area of equal markedness was 45.8cm^2(23%). In Comparison Pattern 3, a sign with luminance level of 300mcd/m^2 in size of 195cm^2 has equal brightness to luminance level 1000mcd/m^2 in size of 46.7cm^2(24%) and the area of equal markedness was 43.3cm^2(22%).

In Pattern 1, (30mcd/m^2, 100mcd/m^2), level of luminance almost tripled (-70mcd/m^2) and its size was reduced to approximately one-third. In Pattern 2(100mcd/m^2, 300mcd/m^2) and Pattern 3, luminance almost tripled, and the size was reduced to approximately one-forth. After the review, there was no significant difference between evaluation of “Equal Brightness", and “Equal Markedness". Therefore, subjects were evaluating almost the same things under different instructions.

Table 1 and **Table 2** shows the corresponding values of equal brightness and equal markedness, in size of 30mcd/m^2 of "195cm^2" as their base value. Viewing angle calculation of the corresponding values by multiplying luminance and its size is also shown.

Table 1. The corresponding values of equal brightness in size of 30mcd/m^2 of "195cm^2" as their base value.

L[mcd/㎡]	S: Area [cm^2]		L×S	D[deg]
	Experimented	Reduced		
30	195	195		4.00
100	64	64	6428	2.30
300	50	17	4950	1.16
1000	47	4	4000	0.57

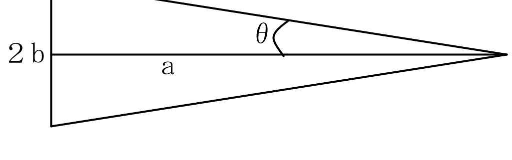
L: afterglow Luminance[mcd/㎡] D: viewing angle[deg]

Table 2. The corresponding values of equal markedness in size of 30mcd/m^2 of "195cm^2" as their base value.

L[mcd/㎡]	S: Area [cm^2]		L×S	D[deg]
	Experimented	Reduced		
30	195	195		4.00
100	59	59	5870	2.19
300	46	14	4140	1.06
1000	43	3	3100	0.50

L: afterglow Luminance[mcd/㎡] D: viewing angle[deg]

From the relation between visual distance and size of the sign as below (**Figure 9.**), we calculated the viewing angle.



a : Visual Distance(cm)
2 b : Length of one side of sign (cm)
2θ : Viewing Angle
tan θ=a/b

Figure 9. Relation of visual distance and size of the sign and its viewing angle

4.3 Size and Installation interval of afterglow phosphorescent signs

From results above, we determined the regression equation of luminance and size to determine the equal amount of brightness (Equation 3) and regression equation of luminance and size to determine the equal markedness (Equation 4).

Equation of luminance and size to determine the equal amount of brightness：

$$S = 9695L^{-1.12} \cdots\cdots\cdots\cdots\cdots\cdots (3)$$

（$R^2 = 0.9961$） S：Size [cm^2]　L：Surface Luminance [mcd/m^2]

Equation of luminance and size to determine the equal markedness：

$$S = 12411L^{-1.1933} \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

（$R^2 = 0.9967$） S：Size[cm^2]　L：Surface Luminance [mcd/m^2]

The relation between luminance and viewing angle is shown in **Figure 9**.
We determined the regression equation from this (Equation 5).

$$D = 31.915L^{-0.5967} \cdots\cdots\cdots\cdots\cdots\cdots (5)$$

D：Viewing Angle[deg]　L：Luminance [mcd/m^2]

The length of one side of a square with equal markedness (visual attractiveness) per luminance level is shown in **Table 3.** This was determined by assigning the value of luminance (L) in equation (5) to calculate the viewing angle (D) and from that, determined the length of one side of the square (cm) at certain viewing distance. For Example, if guide signs are to be placed on electricity polls at intervals of 20 meters, in order to ensure the equal markedness of 18cm lengths per side after 2 minutes (1000mcd/m^2), the required length of one side is 71cm after 20 minutes (100mcd/m^2), and 146cm after 60minutes (30mcd/m^2).

Table 3. The length of one side of a square with equal markedness (visual attractiveness) per luminance level (unit: cm)

L	T	D	Visual distance[m]						
[mcd/㎡]	[min]	[deg]	5	10	15	20	25	30	35
1000	2	0.5	5	9	14	18	23	27	32
600	4	0.7	6	12	18	25	31	37	43
300	7	1.1	9	19	28	37	46	56	65
150	13	1.6	14	28	42	56	70	84	98
100	20	2.0	18	36	54	71	89	107	125
60	30	2.8	24	48	73	97	121	145	169
30	60	4.2	37	73	110	146	183	220	256

L:afterglow Luminance[mcd/㎡] T:elapsed Time [min] D:viewing angle[deg]

5. CONCLUSION

1) From the experiment to walk under the no-light environment, it is clear that afterglow phosphorescent signs and small LED lights functions effectively while evacuating under power failure during an earthquake disaster.

2) As results of our experiments to measure the performance of afterglow phosphorescent materials, Visual attractiveness and visibility of afterglow phosphorescent signs, we found equations to measure the level of afterglow of afterglow phosphorescent materials, visual attractiveness and visibility.

3) The equation to determine the level of afterglow of afterglow phosphorescent material by elapsed time is: $L = 2.8264T^{-1.1455}$ [L: Afterglow luminance(cd/m^2) T: Elapsed Time(minutes)]. From this equation, we can determine the level of luminance of afterglow phosphorescent signs by per elapsed time after a power failure.

4) Relative equation to determine the visual attractiveness of afterglow phosphorescent sign is: $D=31.915L^{-0.5967}$[D: Visual Angle(deg) L: Luminance(mcd/m^2)] By using this equation, various signs with equal visual attractiveness in different luminance level can be created. By combining equations above, we can determine appropriate sizes and installation intervals of afterglow phosphorescent signs while considering the time of evacuation after a power failure.

AKNOWLEDGMENT

This study was conducted as some activity of the outdoor disaster prevention illumination research committee of IEIJ. We than a committee member heartily. This study was partly funded by Grant-in-Aid for Scientific Research (KAKENHI) of Japan Ministry of Education, Culture, Sports, Science and Technology. (Secure lighting for outdoor evacuation and establishment of way guidance system during an earthquake disaster).

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