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Visibility of Emergency Exit Signs and Emergency Lights through Smoke

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Abstract

Emergency exit signs and lights are significant for effective evacuation in case of emergency. However visibility of those signs drops drastically in case of fire because of fire smoke. As reported in the Daegue subway train fire in Korea, lost of visibility causes serious problems for safety evacuation. A series of experiments is conducted to examine the visibility of various kinds of emergency exit signs and lights through fire smoke. Relations between visibility described by visible distance (V(m)) and optical smoke density (Cs(1/m)) are obtained quantitatively as expressed by $V=k_1/Cs+k_2$, where k_i is experimental constant for each emergency signs and lights. Also improvement of the visibility by increasing luminous intensity is examined.

1. Introduction

In case of building fire, fire smoke causes serious problems for safe evacuation. It is well known fact that many victims seem to lose their escape route when exposed to smoke as reported in the Daegue subway train fire. Emergency exit signs are one of the limited counter-measures for effective evacuation in emergency. However visibility of the signs decreases as increasing smoke density even the signs are back-lit type

Visibility of exit signs through smoke was studied by Jin[1] and Collins et al.[2]. And it was found that the visibility through fire smoke is in inverse proportion to smoke density expressed by a simple correlation as follows,

$$V = k\frac{1}{C_s} \tag{1}$$

where V is visible distance in meter , Cs is a smoke extinction coefficient in m^{-1} introduced by Eq.2 as mentioned later, k is the experimental constant of each of signs.

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Jin[1] indicated that k=3 for reflecting type of emergency sign,5-10 for a light emitting sign and 2-4 for a reflecting sign.

In Japan, technical standards of exit signs of back-lit type and reflecting type were changed in 2000, and new types of exit signs are getting popular. Size of new type signs became compact and the luminous intensity decreases. Therefore, the conspicuousness seems to become lower than that of ordinal type of exit signs.

It is our concerns how much the visibility of new type of exit signs is lost compared with that of the ordinary type. However there are not any available data concerned with visibility of exit signs currently in use under smoke condition. Therefore, a series of experiments is conducted to obtain technical data of the visibility through smoke. In addition visibility of various types of emergency lights currently used in special spaces such as ships is also examined.

2. Experiment

2.1 Test Exit Signs and Emergency Lights

Exit Sign

There are two types of exit sign currently used in Japan. One is rectangular and the other is square type. The technical standard of the latter was newly prescribed in 2000 by the notification No.39 of the Fire and Disaster Management Agency. Ordinary type has a light box with internal light source and a pictograph is lit from behind. Whereas, as for the new type exit sin, pictograph is lit from the side section at the top of pictogram plate by using inner scattering effect. There are three sizes, i.e. "small" or "C-class", "medium" or "B-class" and "large" or "A-class", with different light sources respectively.

(option: slit at the bottom for lighting floor)

(a) ordinary type

(b) new type exit sign

Photo 1. Test Exit Signs: *Specification of above exit signs is prescribed by technical standards of the Fire and Disaster Management Agency in Japan.*

Table 1. List of test exit signs (back-lit type)

No.	Type	Size(cm) Height x Width	Average luminance (cd/m^2)
A-1	Small Old type	12.5 x 36.0	700
A-2	B class	22.5 x 22.5	800
A-3	C class	14.0 x 14.0	250

In the experiment, a "small" size ordinary rectangular sign was used as shown in Photo 1. Inner light source was one 10- W fluorescent light tube and average luminance on the surface was about 700 cd/m^2. As an option specification, this test exit sign had a small slit at the bottom of the light box which lit the floor.

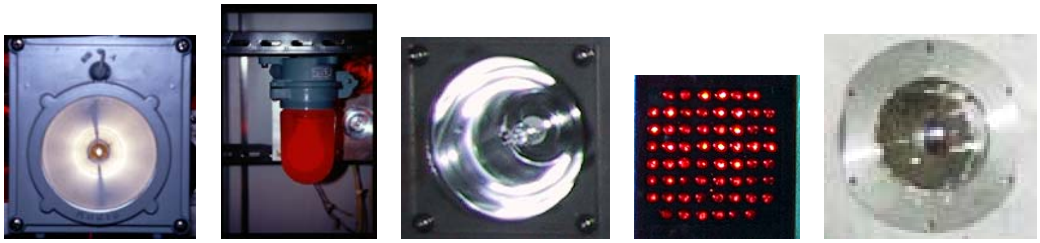
Two square type exit signs prescribed as "C-class" and "B-class" were used. In these new type exit signs, a CCFL(cold cathode fluorescent lamp) of 2W and 3W was used respectively. Each of the new type signs corresponds to the "smaller" and "medium" size of ordinary type, however the width and average luminance became 1/3 of the

ordinary type as shown in Tab.1.

Emergency Lights

There are various emergency lights in different fields. Main purpose of the lights is to reserve light in case of power failure. And it is also expected to work for aiding evacuation where no exit signs are equipped such as engine room of ships etc. The configuration of the emergency light, i.e. size, color and luminance etc., is different from the exit sign as above, and the visibility and the conspicuousness through smoke seem to be different.

In this experiment, seven types of emergency lights were used as shown in Tab.2 and Photo 2. Three of them are currently used in ships and four are prospective emergency lights under development. Visibility of theses lights is examined with and without red-colored filter respectively except red LED lights to know the effect of color on visibility.



B-1 B-2 B-3 (B-4)*1) B-6 (B-5)*2) B-7

Photo 2. Outlook of test emergency lights. **1) B-4 is the same as B-3 except power of Halogen bulb. *2) B-5 is the same as B-6 except color of LED elements*

Table 2. List of test emergency lights

No.	Type	Purpose	Light source area		Red colored filter	Max. luminance (cd/m^2) *1)	Illuminance (lx) *2)
			Shape	Size (cm)			
B- 1	ordinary Emergency light	Emergency Light and Exit Sign used for Ship	Round with reflector	9.5	none	10,000	7
					attached	1,800	1
B-2	hanging lamp	Emergency Light	paraboloid type	13.0	none	1,000	3
					attached	300	3
B-3	halogen lamp1	General purpose (unidirectional)	Round with reflector	5.5	none	10,000	690
					attached	30,000	69
B-4	halogen Lamp No.2	General purpose (wide-directional)	round with reflector	5.5	none	60,000	34
					attached	6,000	3.1
B-5	white LED	Trial Product for emergency light with LED	Square with 76 LED lights	6.0	none	256,000	331
					attached	27,360	15
B-6	red LED	Trial Product for emergency light with LED	Square with 76 1 LED lights	6.0	N.A.	4,000	23
B-7	MIL standard Emergency lamp	Emergency Light based on US military specification	Round with reflector	10.0	none	16,230	103
					attached	2,018	90

**1)Luminance is measured by a spot luminance meter and max. luminance is the highest reading on the surface of light sources.*

** 2) Illuminance is measured at 1 m away from the center of emergency sign in the facing direction to the sign.*

2.2 Experimental Setup

Equipments

Experiment was conducted in an experimental corridor of 24m long, 1.9 wide and 2.6m height. Each of the exist signs and emergency lights was located at the end of the corridor at 1.8m from the floor level for exit signs and 1.5m for emergency lights as shown in Photo 3 and Fig.1. During the experiments, there were no light sources except the exit sign or the emergency light.

The corridor was filled with artificial white smoke. The smoke was generated by two standard generators generally used for entertainment and /or rescue training . The smoke is made of harmless polyglycols and water mist. Characteristic of the smoke generator is listed in Tab.3. Smoke generators were located in the middle of the corridor and two fans were used to distribute the smoke uniformly in the corridor.

Smoke density was measured by using light extinction beam photometers so called smoke meter based on JIS A1306 [3]. The light beam length was 1.0 m and Se photo sensor was used. Extinction coefficient as representing optical smoke density was calculated by using the following expression.

Table 3. Specification of smoke generator

Product name	Rosco 600 (Coburn Japan Corp.)
Mist size	0.25-60 μm
Smoke type etc.	A)Stage & Studio type Liquid Aging: retained as mist for about 3min. B) Standard type Liquid.* Aging : about 10-15 min. (Both smoke are not irritant and have weak smell of burnt oil)

**B) type smoke was used in two cases , i.e. B-5 and B-7 without red filter as listed in*

Photo 3. Outlook of experiment setup at the end of corridor.

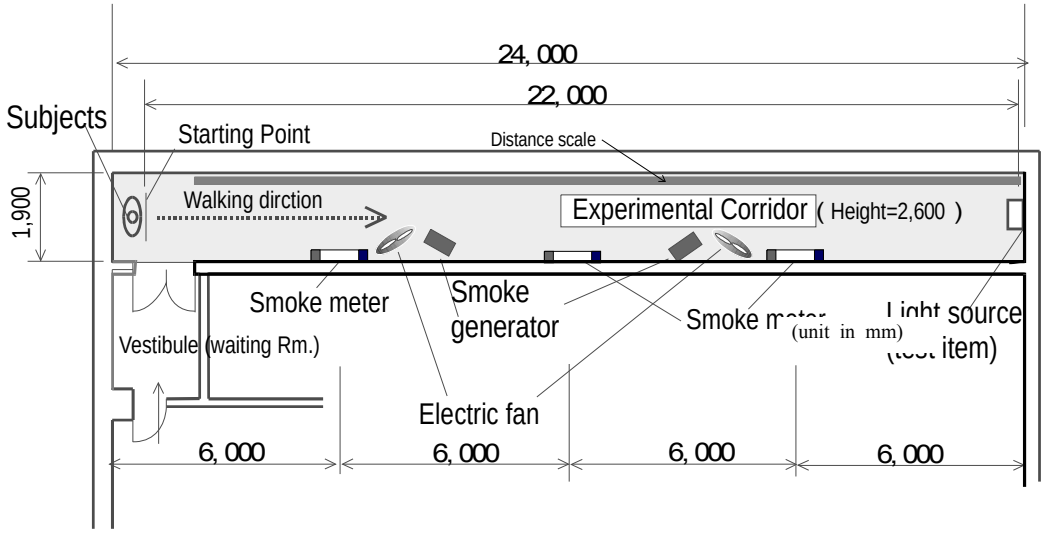


Figure 1. Outline of experiment setup.

$$C_s = \frac{1}{L} \ln \frac{I_0}{I} \quad (2)$$

where L is the light beam length, I_0 is the light intensity to the photo sensor without any smoke and I is the measured intensity through smoke.

Three smoke meters were located at 6m, 12m and 18 m from test items and 1.5 m above floor level. Along the light beam, smoke meters were partly covered by black paper so that the beam could not to be seen directly by subjects. Because, the beam of the smoke meters may give effects on the visibility as background light noise as indicated by Jin et al.[4]. These equipments are located according to the experimental set up shown in Fig.1.

Visibility of exit signs

Before experiment started, the corridor was filled with smoke and the smoke density was monitored to reach to a certain level. For each of experimental runs, a subject was asked to enter the corridor and to wait for more than 1 min. at a starting point with eye mask to adapt darkness. And then subject was asked to walk towards the test item to be observed. When the test item was visible and possible to recognized as an exit sign or emergency light, the subject wrote down the time and the distance to the test item by referring a scale on the floor with a flashlight.

During the experiment, smoke density data were logged on PC. And the data at the time when subjects noted were referenced for estimating the extinction coefficient, because the smoke density varied during each run. Then average data of two smoke meters or specific one which located between subject and test item were used for following analysis.

After recognition of the test item, the subject returned to the starting point and the same procedure was repeated for others. In this experiment, total 18 males and two females aged between 24 and 60 participated as subjects.

3. Results and Discussions

Visibility of exit signs

The relation between visibility and smoke density is examined. Fig.2 indicates that the visibility of exit signs is in inverse proportion to the smoke extinction by Jin[1] and other researches[2] expressed by Eq.(1).

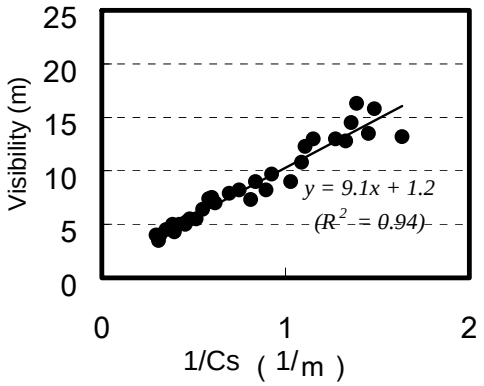
The correlation was derived from experiments by using fire smoke, however nearly the same correlation can be obtained with artificial smoke. The data indicated by Jin [1] were scattered with uncertainty, however the correlation expressed by Eq.(3) in this experiment is more precise and gives good fit to the data. Correlation coefficients (R^2) is over 0.93.

$$V = k_1 \frac{1}{C_s} + k_2 \quad (3)$$

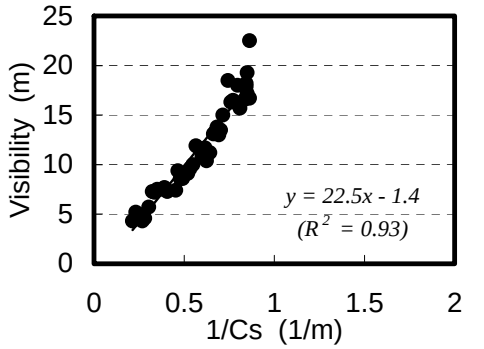
where k_i is experimental constant for each exit signs or emergency lights introduced by the least square method.

There are not much difference between Eq.(1) and Eq.(3) practically, however the constant k_1 corresponding k in Eq.(1) seems to be larger than the data indicated by Jin [1] in spite of the difference of test items. One of the reasons is that this experiment was conducted without background light sources. In general, background light is scattered by smoke, especially white smoke, which makes less light contrast of emergency light against background and causes visibility drop. The other reason is that the artificial smoke is not irritant, which is crucial when the smoke is white as indicated by Jin et al.[5].

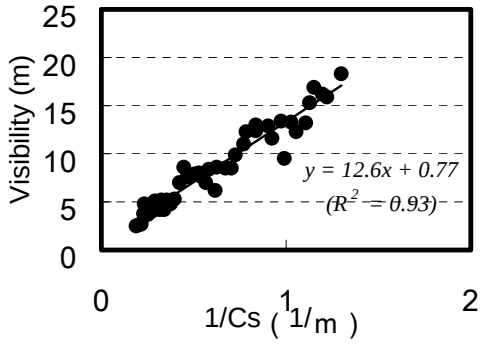
Contrary to our expectation, the visibility of "C-class" is better than the ordinary "small" exit sign, even the size and the luminance of the "C-class" is less than the "small" type exit sign. We suspect that the light emitting from the slit at the bottom of the light box scattered in surroundings and it increased background light noise. And then this reduced visibility as above mentioned. Further study will be needed for understanding this effect.



(a) Ordinary "Small-Size" Type



(b) "B-class" emergency exist sign



(c) "C-class" emergency exist sign

Figure 2. Correlations between visibility vs. inverse of extinction coefficient.

The result also indicates that variance of visibilities between different exit sign is relatively large, when smoke density is low and vice versa. For example, the visibility of "B-class" is twice as high as that of the ordinary "small" type exit sign, when *Cs* is 1.0. However, when the smoke is thicker, the absorption of light through smoke is so large and much difference can not be seen, i.e., the visibility of B-class is 6.1 m and A-class is 4.2 m when *Cs*=3.0.

Visibility of emergency lights

The same correlation as expressed in Eq.(3) is examined for emergency lights. The slope(k_1) and the intercept (k_2) of the regression linear function and its correlation coefficient are listed in Tab 2. The correlation coefficients are relatively high between 0.86 and 0.97and the result indicates that the same correlation can be applied to all tested emergency lights.

In 13 cases, visibility of B-2 and B-3 type using halogen lamp shows relatively high, whereas visibility of the ordinary emergency lights of B-1 is the lowest. Visibility of LED white type is in the middle, even the maximum luminance is the highest.

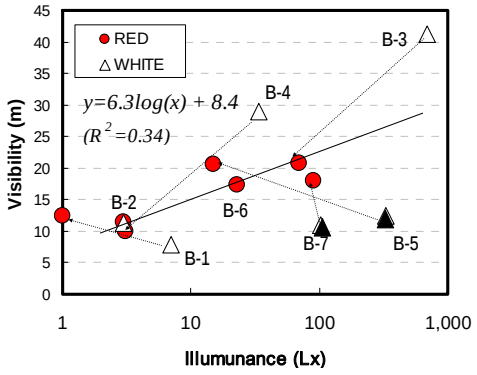
Jin et al.[4] indicated that the conspicuousness of exit signs increases with increasing luminance and view angle associated with area of the sign. Also the result indicated that semantic degrees of conspicuousness seem to be expressed by a logarithmic function of the luminance of exit sign.

In this experiment, there are variety of light conditions, i.e. distribution, luminance and color etc. For example, maximum luminance of the LED type(B-5) is higher than that of halogen lamp (B-3) and the distribution is very narrow. However the total luminance intensity is weak , so the luminous flux is smaller than that of halogen lamp. Our hypothesis is that the visibility depends on the average luminous flux which is represented by the average illuminance as listed in Tab.2.

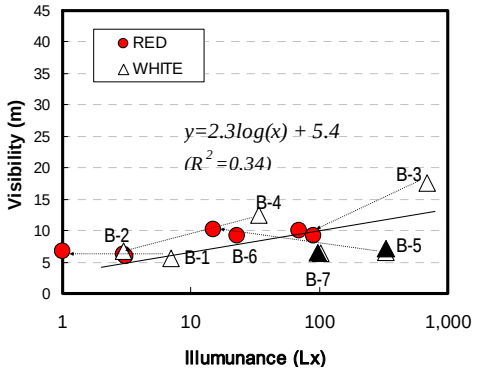
Fig.3 shows the correlation of the visibility and the illuminance. Plots of visibility is calculated by regression linear function in Tab.3 under given value of Cs.
The correlation between the visibility and the illuminance can be expressed by logarithmic function as indicated in this figure. This correlation is distinguished when the smoke is thin. The data of white color lights are somewhat scattered compared with red ones. Blacked data of B-7 and B-5 were obtained with different kind of smoke which was used in the exit sign experiment. This condition may give effect on lower visibility compared with others. Also configuration of emergency lights, i.e. light source, distribution of light, may give effects. These are remained for future studies.

When smoke becomes thick, the visibility of any emergency lights drops and no distinguished effect of luminance flux on visibility can be seen. This tendency is also recognized in case of emergency sign as already mentioned.

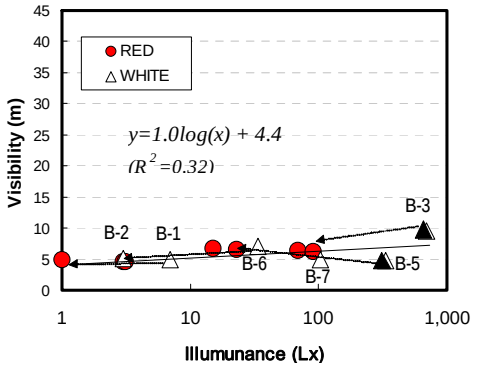
It is known fact that longer wave-length of light gives less absorption through smoke, i.e. red is easy to see under smoke condition. Some of the plots in Fig.3 indicated that the visibility increase when red filter is attached. However this is not always true. The visibility depends on both color, luminance intensity and view angle etc. Further studies will be needed to distinguish quantitatively between these effects on visibility.



(a) Cs = 1.0



(b) Cs = 2.0



(c) Cs = 3.0

Figure 3. Correlations between visibility vs. illuminance under various smoke density condition : *The plots are calculated with regression linear functions listed in Tab.3.*

Table 4. Correlations between visibility(V) of the emergency lights through smoke vs. inverse of extinction coefficient(C_S): $V=k_1/C_S+k_2$

No.	Type	Red colored Filter	Regression linear function		Correlation coefficient	Number of plots
			Slope (k_1)	intercept (k_2)	(R^2)	
B-1	Ordinary Emergency light	None	4.5	3.4	0.92	24
		Attached	11.4	1.1	0.88	46
B-2	Hanging Lamp	None	9.2	2.1	0.86	45
		Attached	10.2	1.2	0.88	35
B-3	Halogen lamp No.1 (4.8V13w)	None	47.6	-6.3	0.89	30
		Attached	21.7	-0.9	0.94	39
B-4	Halogen lamp No.2 (4.8V 4W)	None	32.9	-3.9	0.89	33
		Attached	8.1	1.9	0.89	31
B-5*	White LED	None*	11.5	0.9	0.95	48
		Attached	21.0	-0.3	0.97	29
B-6	Red LED	NA	16.3	1.1	0.94	47
B-7*	MIL standard Emergen cy lamp	None*	8.9	2.0	0.95	38
		Attached	17.7	0.3	0.90	25

* "Standard" type liquid is used to generate smoke in two cases without filter.

5. Conclusion

The visibility of exit signs and emergency lights through artificial smoke was examined by experiment. In general, results indicate the similar correlation between the visibility and fire smoke introduced by previous studies. However the obtained correlation by using artificial smoke seemed to overestimate the visibility. The reason is attributed to this experimental condition, i.e. darkness and usage of non-irritant smoke. The visibility of lights in darkness is improved compared with the visibility under light scattered smoke condition. It was believed that the area of sign is important; however the visibility of smaller and less bright exit sign such as "C-class" is nearly the same as that of the ordinary exit sign in dark condition. It is recognized that the contrast between the sign and background is also important factor for the visibility.

As for the emergency exit light, there are various kinds of light type and the visibility varies type to type. The visibility depends on luminous intensity, distribution of light and color. The visibility increases with increasing luminous intensity. And read color is more visible than white one when the luminous flux is the same magnitude. However the tendency is distinguished while the smoke is relatively thin i.e. Cs =1.0. While the smoke is thick over 2.0 , visibility drops very much in any cases and there are not much difference between any exit signs and emergency lights.

It should be remarked that in real fire, *Cs* over 1.2 is very difficult condition for evacuation in real fire from both physical and physiological aspects. For this reason, the guiding effect of existing emergency exit signs and emergency lights can be expected in thinner smoke but not in thick smoke condition. Other guiding tools including directional oral guiding systems should be developed for improving safe evacuation, if effective guiding tools are expected to operate even in thick smoke.

References

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List of Figures, Photo and Tables.

Figures

Photos

Tables