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Visual Condition at Sea for the Safety Navigation

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ABSTRACT: To the navigation officers of the watch (OOW's) on the navigation bridge the environmental condition of visual acuity is the most important factor for keeping a proper look-out, as regulated by the IMO COLREG's (Rule 5). Navigation officers are required to keep a proper look-out for prevention of (ships) collisions. There are many collision incidents at sea, and especially so under conditions of good visibility. This paper has two topics related to the illuminance and luminance from sunlight, as follows:
The first topic is the introductory explanation of the illuminance inside the navigation bridge.
The second topic is the sky luminance condition as seen by the OOW from the navigation bridge.
These two topics are fundamental factors related to visual perception at sea. The OOW on the bridge has to understand that every care must be taken, especially in fine weather conditions.

1 INTRODUCTION

1.1 *Navigational visual condition at sea*

The meaning of the navigational visual condition at sea is the environmental condition by eye-sight at sea. The visual perception of the target at sea in the maritime traffic system is herein considered, based on the following two measurement results:

1 horizontal illuminance inside the navigation bridge
2 sky luminance of 2 degrees within the horizon

In addition, the visual perception of targets such as aids to navigation and ships is directly related to environmental physical characteristics.

1.2 *A proper look-out*

As you know, Rule 5 of the COLREG's (International Regulations for Preventing Collisions at Sea, 1972) define "Look-out" as follows: Every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

1.3 *Marine accidents caused by the improper look-out*

An improper look-out is often pointed out as a cause of marine accidents. Fig. 1 shows the annual change of the total number of marine accidents and the ratio of improper look-out, based on data collected by the MAIA (Marine Accident Inquiry Agency) in Japan, years 2000 ~ 2008.

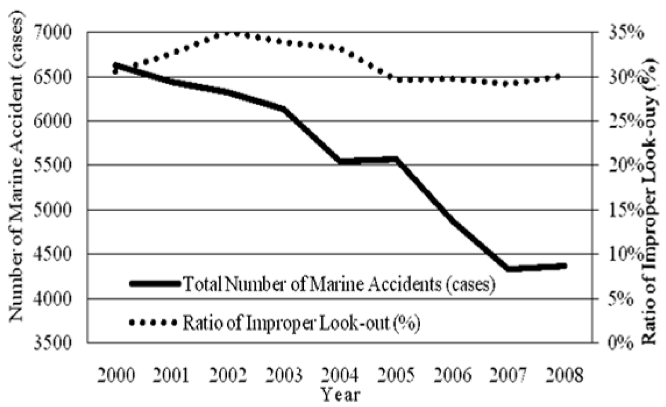

Figure 1. Marine accident caused by improper look-out

2 OBSERVATION

2.1 *Horizontal illuminance in the navigation bridge*

The Captain, navigation officers, look-outs and helmsmen (hereafter termed "navigators") on watch on the navigation bridge are strongly affected by the effect of natural lighting such as sunlight. The illuminance outdoors by day and by night has a wide variance between 100,000 lx from direct sunlight in fine weather and by 0.2 lx from the light of a full moon.

The illuminance meter (model IM-3 made by TOPCON Co. Ltd.) as a measurement device connected with a recording printer was used as indicated in Photo 1. There was no additional condition which had a restriction, such as alteration of the course, speed or others, during this measurement of illuminance on the navigation bridge.

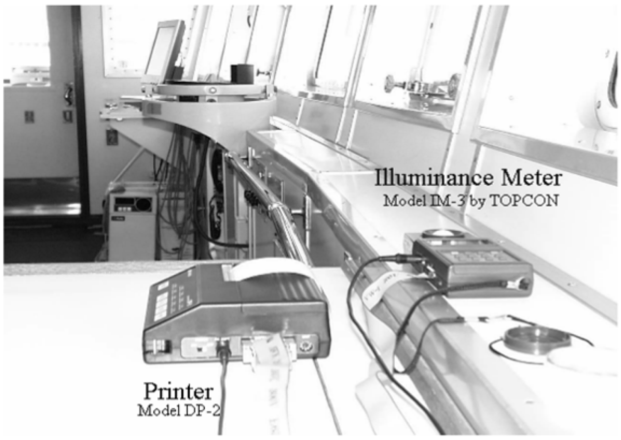

Photo 1, Measurement device

Table 1. Specification of the cooperative ships

Month	Ship	Purpose	G.T. Tons	L.O.A. m	Speed knots	H.E. m
March	C	T	449	49.95	13.5	7
May	A	CF	3,611	114.50	19.5	14
June	B	CF	19,796	192.90	21.8	22
July	C	T	449	49.95	13.5	7
Sept	D	CF	3,597	196.00	25.0	23

Remarks
1) T: Training ship, CF:Car Ferry, H.E.:Height of Eye
2) Observing area was around Japan. Latitude: 35degrees N.

2.2 *Sky luminance in 2 degrees from the horizon*

One of the conditions to recognise a target, such as a ship or aid to navigation, is the background luminance of the object. It is necessary for visible perception that the difference of the luminance between the background and the target should be more than the value of the luminance difference threshold.

The luminance difference threshold means the threshold limit value of the brightness, based on the experimental studies by Blackwell, H.R., in 1946 and Narisade, K. et al, in 1977 and so on.

About a background when we look at a target, it can be judged from the navigators' characteristics of eye movement at sea. This background is both the sky luminance of 2 degrees above the horizon and sea surface luminance of 2 degrees below the horizon, but in this paper the sky luminance is taken into consideration.

The measurement was carried out on board ship C. The luminance meters (TOPCON's meters BM-5, BM-5A and BM-8: Photo 2) were set and directed right ahead through the windscreen of the navigation bridge according to the regular procedure by navigators. The specification of luminance meter BM-5A is shown in Table 2. The weather conditions were fine, or fine and cloudy, with direct sunlight.

Photo 2. Luminance Meters

Table 2. Specification of the luminance meter(BM-5A)

Optical System	Diameter 32 mm, F=2.5
Measurement Angle	0.1, 0.2, 1, 2 degrees
Photo acceptance Unit	Electronic Light Amplifier
Wave Length	380-780 n.m.
Range	0.0001～1200000cd/m2
Distance	520mm～∞
Sampling Time	2 sec
Size & Weight	355(L) X 130(W) X 169(H) mm , 4 Kg

3 RESULTS

3.1 *Horizontal illuminance on the navigation bridge*

The result of the measurement data of the horizontal illuminance on the navigation bridge using the illuminance meter connected with a printer, as indicated in Photo 1, is shown in Fig. 2. The vertical scale in Fig. 2 shows illuminance in lux in logarithmic scale; the horizontal scale shows Japan Standard Time (JST) which has 9 hours difference from Greenwich Mean Time (GMT). These data have dispersion which depends on the different observing times in a month.

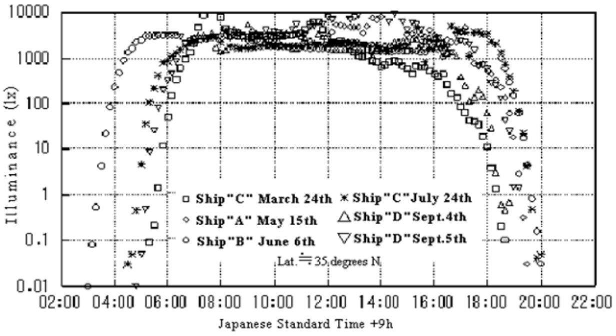

Figure 2. Horizontal illuminance in the navigation bridge

3.2 *Sky luminance of 2 degrees above the horizon*

The sky luminance, dependent on the relative direction towards the solar direction in the open sea, was measured. The result of these observations is shown in Table 3. These experimental observations were carried out in July during a research voyage of the training ship.

Table 3 Sky luminance of the relative direction towards the solar direction at open sea

Relative Angle degrees	Max.:A cd／m^2	Min.:B cd／m^2	Range:A-B cd／m^2
0	27,420	7,070	20,350
45	20,900	6,610	14,290
90	6,627	4,723	1,904
135	5,500	3,960	1,540
180	6,165	4,166	1,999
-135	6,095	3,910	2,185
-90	6,170	4,249	1,921
-45	12,190	6,340	5,850

Remarks: Relative angle 0 degree means the solar direction.
"-(negative number)" means the left side of solar direction

The sky luminance, dependent on the relative direction towards the solar direction at the time of relative angle around 0 (zero) degrees, changes from 7,000 to 27,000 cd/m^2. The range, which means the difference of luminance between the maximum value at A and the minimum value at B, was found to be approximately 20,000 cd/m^2.

The opposite side, in the case where the relative angle is -90 ~ +90 degrees of solar direction, produced a small change at 1/10th of the range.

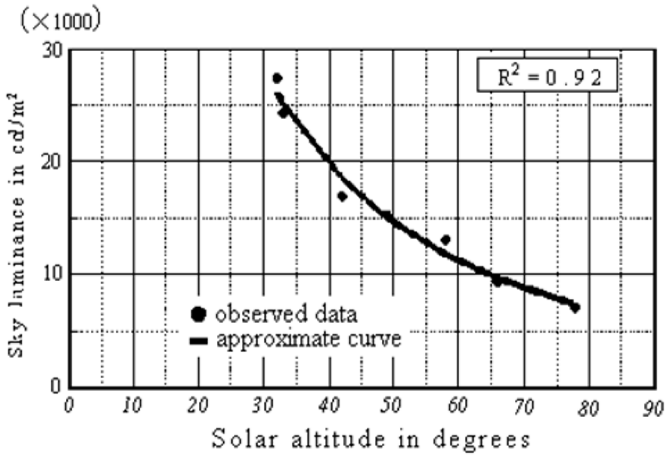

Figure 3. Relationship between the sky luminance and the solar altitude in degrees.

4 CONSIDERATION

4.1 *Horizontal illuminance by the standardization with using solar altitude*

Fig. 2 shows the seasonal difference for times of sunrise and sunset; also, the difference in hours of morning or evening twilight at differing sea areas.

There is no affect by the different heights of eye on the horizontal illuminance on the navigation bridge. The illuminance change in daytime has a wide value between 1,000 lx and 10,000 lx, but at morning or evening twilight the illuminance changes rapidly with time. This is a remarkable feature of twilight – at this time there are functional changes of both the cone and the rod of the visual cell.

The horizontal illuminance nearby the windshield on the navigation bridge has various changes between 0.01 lx and 10,000 lx, according to the voyage situation such as seagoing area, navigation time, ship's course and so on.

Because the illuminance change has seasonal characteristics according to the times of sunrise, sunset and the hours of twilight, standardisation of illuminance based on the observation time might be difficult. Therefore, the solar altitude is useful for the standardisation – by using calculated solar altitudes based on the observing time and geographical position.

Fig.4 shows the results of the standardisation by using solar altitude. This demonstrates that the solar altitude is a suitable factor for explaining the change of horizontal illuminance on the navigation bridge.

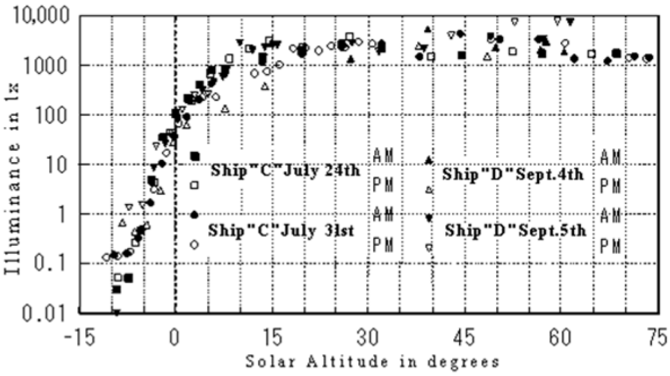

Figure 4 Horizontal illuminance on the navigation bridge by the standardisation method using solar altitudes

4.2 *Sky luminance on shore*

For the purpose of comparing the luminance at sea and ashore, the example of illuminance measurement at Fukui prefecture in Japan is taken into account (Ref. Lighting Handbook published by the Illuminating Engineering Institute of Japan)

Fig.5 shows this example which had no observation data under 5 degrees on shore. In this figure, the line on the celestial sphere via the sun and the (observer's) zenith is characterised as bilaterally symmetric, the maximum point being marked as " X " near the sun and the minimum point, 90 degrees distant via the zenith, as" ● ".

4.3 *Sky luminance at sea in fine weather*

The sky luminance in the relative solar direction is shown in Fig.6 according to the solar altitude. The numbers indicated around this radar charted figure show the relative angle in degrees and the numbers indicated on the radial axes show the sky luminance in cd/m^2.

The distribution of sky luminance to each relative solar direction in fine weather (with sunlight) gradually becomes concentric circles. When the solar altitude is more than 60 degrees the variability of the luminance is small, so the background condition of the visual perception is uniform.

Comparing with the case on shore (Fig. 5), it is understandable that items have similar conditions, as follows:

1 There is a maximum point of the sky luminance relative to the solar direction.
2 There is a minimum point in the opposite direction to the maximum point (when the relative solar direction is near 180 degrees).
3 The line on the celestial sphere via the sun and the zenith is characterised as being bilaterally symmetric.
4 The distribution of the sky luminance has uniformity with no relationship to the relative solar direction, nor to the solar altitude.

These items are the evidence to support the navigators' statements which explain that it is easy to recognise targets visually when "the sun is behind me, not in front of me".

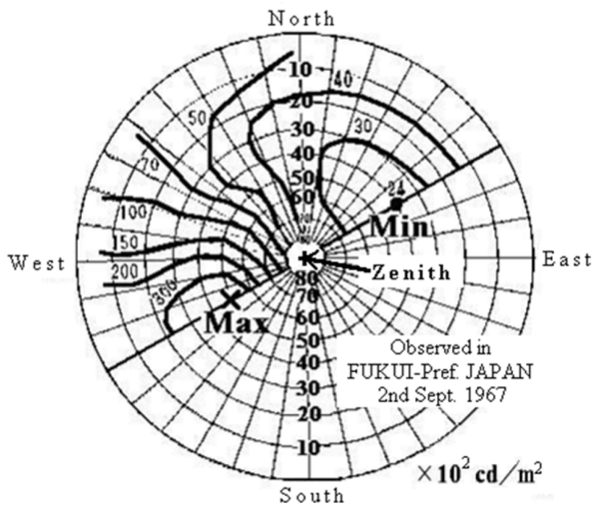

Figure 5 Example of the sky luminance on shore

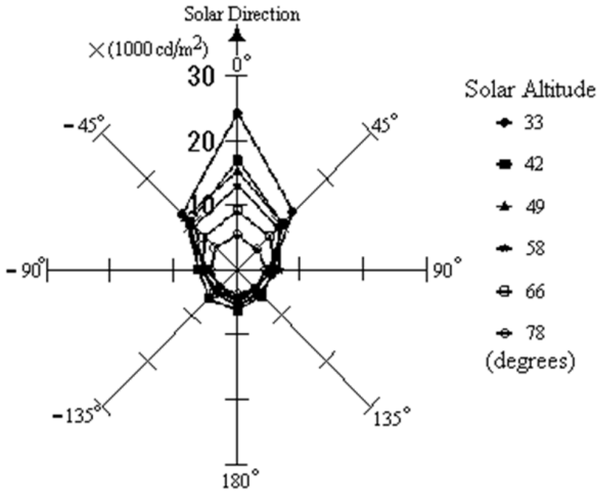

Figure 6 Sky luminance in the relative solar direction

4.4 *Sky luminance of the solar direction*

The approximate curve as shown in Fig.3 is taken into consideration. The fractional approximate curve of the sky luminance of the solar direction related to solar altitude can be explained by the formula as shown hereunder (1).

$$Y = a/X + B \qquad (1)$$

where, Y=sky luminance in cd/m^2; X=solar altitude in degrees; a=105 (coefficient); b= -5,000 (constant).

According to Fig.4, this formula can be applied when the solar altitude is more than 10 degrees.

4.5 *Relationship between the solar altitude and ship's collision*

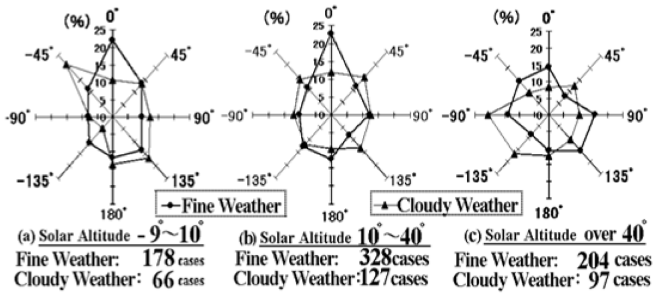

Figure 7 Impact by the Solar altitude and the relative direction on the ships' collision

According to the result of analysing 1000 cases((a)244, (b)455, (c)301) of ships' collisions, Fig. 7 can be obtained as an impact by the solar altitude and the relative direction toward the solar direction.

The solar direction in the case of less than 40 degrees of the solar altitude has a direct effect to the ships' collision.

The OOW should remind not only the solar direction but also fine weather. Generally speaking, we believe that the fine weather is good weather, but fine weather might have the blind spot so-called "white hall" which means the restricted visual condition for the proper look-out by the OOW at sea.

5 CONCLUSIONS

The navigational visual, environmental background condition of recognising targets (so-called 'visual perception') by sight at sea has been taken into consideration.

There are 4 conditions which should be considered, as shown hereunder, in order to discuss the visual perception:

1 Luminance of a target
2 Luminance of the background
3 Adaptation condition of the (observer's) retina
4 Equivalent Veiling Luminance from the near visual field

In this study the authors have focused on the above item 2) – luminance of the background – because of the necessity for the field of study on board ship.

5.1 *Illuminance on the navigation bridge*

The horizontal illuminance on the navigation bridge can be standardised based on the solar altitude, as shown below in table 4:

We can understand the illuminance condition of foreside on the navigation bridge. The start and end of navigational twilight is -9(minus nine) degrees.

Table 4 Horizontal illuminance on the navigation bridge

Solar altitude degrees	Horizontal illuminance lx
over 10	1000 ~10,000
10	1000
0	100
-3	10
-6	1
-9	0.01 ~ 0.1 *
-18	Start and end of astronomical twilight

Note * The horizon cannot be seen except in the solar direction at the start and end of navigational twilight.

5.2 *Luminance condition for the OOW*

The sky luminance at 2 degrees above (and below) the horizon is one of the most important composition factors of visual perception at sea.

The authors obtained the remarkable features on the sky luminance based mainly on the experimental observations on board, and these are shown as follows:

1 The value of the sky luminance at 2 degrees above the horizon is bigger than the sea surface luminance, except in cases of sun-glitter on the sea surface
2 The sky luminance of the solar direction has various changes between approx. 7,000 and 27,000 cd/m^2;
3 The sky luminance of the solar direction related to the solar altitude can be explained when the solar altitude is more than 10 degrees by this formula:

   Y = a/X + B

   where, Y=sky luminance in cd/m2; X=solar altitude in degrees; a=105 (coefficient); b= -5,000 (constant).
4 The distribution of sky luminance to each relative solar direction gradually forms concentric circles. When the solar altitude is more than 60 degrees the variability of the luminance distribution is small and the background condition of the visual perception can be said to be uniform
5 The distribution of the sky luminance on the opposite side of the solar direction has uniformity, with no relationship to the relative solar direction nor to the solar altitude. This is the evidence to support navigators' statements which say that it is "easy to recognise targets when the sun is behind the observer".
6 The OOW should think of the "white hall" which means gimmick of the proper look-out especially in fine weather.

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