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Contrast threshold research of small target visibility in road or tunnel lighting environment

Huang Ke[1,2]*, Weng Ji[1]
[1]Faculty of Architecture and Urban Planning, Chongqing University, Chongqing, 400045, (CHINA)
[2]School of Civil Engineering and Architecture, Southwest University of Science and Technology, Mianyang, 621010,
(CHINA)
E-mail: 5561738@qq.com

ABSTRACT

The lighting design, construction and acceptance of road or tunnel are based on "The standard of ventilation and lighting design for highway tunnel" and "Outdoor Lighting Measurement Methods". Which determined the methods: measured the point set on the road line with the luminance meter from a small field angle. This method only concern a few measuring points, but not the surrounding environment, so, it cannot reflect the vehicle drivers actual visual experience. This paper takes the small target visibility visual indicator into road and tunnel lighting evaluation system. Based on luminance threshold contrast simulation model, it analysis the positive and negative luminance contrast conditions and fits out the relationship between the identification probability with relative contrast. By increasing the contrast, can increase its visibility, so as to create better conditions for road transport safety.

KEYWORDS

Transport; Road lighting; Luminance; Contrast; Visibility.

INTRODUCTION

Road lighting creates a good visual environment for the motor vehicle drivers in order to achieve traffic safety, improve transportation efficiency and beautify the city in the night. However, on the condition of ensure the safety and comfort of driving, the green and low-carbon economic development requires us to further reduce the energy consumption of tunnel lighting in order to achieve the aim of green lighting and sustainable development.

The design, construction and acceptance of the existing road and tunnel lighting take *Tunnel Design Specifications*[1] and the *Outdoor Lighting Measurement Method*[2] as the basement. For outdoor lighting measurements, in accordance with the specification, it measures the data of the distributions in the plane through the luminance meter small field angle and calculates it. However, this kind of approach which uses one point represents an area cannot reflect the real visual experience of the drivers, because it only concerns the several measuring points of the pavement, and doesn't take the impact of the surroundings into account. This paper introduces the small target visibility, a comprehensive visual indicator into the evaluation system of road and tunnel lighting, and discusses the identifiable conditions of the small targets which meet the threshold contrast with the simulation model of threshold contrast.

This paper simulates the contrast that can identify the small targets with different background brightness. By calculating ΔL the difference between the brightness and object, and C the brightness contrast, it has found that there is a close connection between the background brightness L_b and logarithm C.

This paper finds that: increase the contrast, the visibility of small objects can be improved so as to create better conditions for traffic safety; under the same lighting conditions, the dark objects is easier to be identified than the bright ones when the absolute value of the difference between the brightness of objects and background are same; in the same identical conditions, the dark object can be identified in a lower brightness, when the absolute value of the difference between the brightness of objects and background are same.

This paper is organized as following: In the second chapter, it introduces the current road lighting indicators. In the third chapter, it presents the small object visibility theory and its calculation. In the fourth chapter, it describes the threshold contrast pilot program. In the fifth chapter, it analyzes the experiment data and the actual verification. Finally, it comes to the conclusion in the sixth chapter.

LIGHTING INDICATORS

The tunnel lighting technology and basic research work had been carried out relatively late in China. Before 2000, China's tunnel lighting system primarily follows Road Tunnel Design Specification"[1] (JTJ 026-90). The specification regulates the single lighting length in the tunnel and the minimum brightness of the road. And the same in 1990s, the CIE, short for *Commission Internationale de l'Eclairage*, proposed that the average luminance value of the middle section shall be based on traffic and parking distance[3].

With the development of economy and increase of operational requirements, the country realized that the design standards carried out in 90th need to be improved. In January 2000, based on the existing experience, and the successful experience and advanced technology of road tunnels from other countries, China issued the "Highway Tunnel Ventilation and Lighting Design specifications" (JTJ 026.1-1999). The specification introduced the lighting system structure, tunnel lighting segment length and the brightness, evenness of illumination total longitudinal evenness, lamps and their layout, illuminance and luminance calculation, and other aspects[4].

From practical experience, as to the level of illumination or the evaluation of light environment, the most convenient measurement is most illumination photometry, but it cannot reflect the perception of the human eye; brightness index is much more direct than luminous contrast ratio index, but it has a higher requirement on the equipment. During the measuring process, in addition this kind of evaluation which uses one point represents an area still has considerable limitations.

VISIBILITY OF SMALL OBJECT

The primary purpose of road or tunnel lighting is to ensure the motor vehicle safety. Surface brightness is not sufficient to make the driver see the object on the road. The difference between the brightness of objects and background must higher than a certain minimum value. Visibility level is often used to illustrate visibility, which indicates the difference between the object and the background brightness, the target and its background brightness difference of the luminance difference threshold when multiple in formula (1).

$$VL = \frac{\Delta L}{\Delta L_0} \quad (1)$$

Where: VL - visibility level;

ΔL - the difference between the brightness of object L_t and background L_b. $\Delta L = L_t - L_b$;

ΔL_0 - the difference between the luminance of threshold L_{t0} and background L_b, that is the threshold brightness difference is $\Delta L_0 = L_{t0} - L_b$.

Without considering the color, object brightness contract formula (2), constituted by the brightness of object and background, is the essential factor in identifying obstacles. If the brightness of obstacles is close to that of the background, no matter how high surface brightness is, the visibility is very low, and it is likely to cause traffic hazard; whereas if the brightness contrast of obstacle and background is large, the driver can see and yield to the objects[5].

$$C = \frac{L_t - L_b}{L_b} = \frac{\Delta L}{L_b} \quad (2)$$

Blackwell's experiment on visibility in 1946 is comparatively well known. He spent two and a half years on contrast thresholds of normal human eyes under the request of the Ministry of Scientific Research and Development. One basic step of the experiments is projecting a spot on a white screen which is 60 meters way from a group of observers, and then ask these observers if they saw the spot or not. With different brightness light stimulation experiments, he collected a large number of data from the subjects, and then made a statistical analysis of these data to determine the contrast threshold of the human eyes [6].

Later, Janoff has found that visibility index is much better than their any other optical measurement methods in nighttime accident rate forecast, that is, visibility index contrast or brightness is more suitable for nighttime traffic lighting[7,8].

In 1981, CIE's Report No. 19 makes the visibility level (VL) a terminology to describe a condition that visibility exceeds the threshold[8]. Its definition is that a ratio between a standard object's actual illuminating contrast and illuminating contrast threshold under the CIE's standard conditions[9].

In 1989, based on Blackwell, Aulthorn and his own research, Adrian put forward a new visibility model. He defines it as the ratio between the actual illuminating difference and illuminating contrast threshold difference. Adrian's standard target object is known as small targets[10].

The latest American National Standard Practice for Roadway Lighting RP-8-00 proposed small target visibility criteria[11]. Visibility means the degree of difficulty for the human eye to identify the existence or the shape of the targets. In a simple word, it means the clarity of seeing the targets. Visibility level representation of the target and the background luminance contrast threshold luminance contrast with its multiples; and can be placed in the driver's (eyes off the road 1.45m high, the 10 observation angle) Front (83.07m) different surface brightness position of the small target reflection plate (size of 0.18m × 0.18m, the surface light reflectance ρ = 0.5, a viewing angle of 7.45 '), to calculate the weighted average of the level of visibility, which is a measure of the visibility of the small target object (STV)[11,12].

American National Standard Practice RP-8-00, published in 2000, shows that a 60 years old person with normal vision needs 0.2 seconds to see a still small target with uniform brightness. The main factors includes: the brightness of the target, the nearby background brightness, adaptation of the surroundings, disability glare and Est. The accurate visibility of small targets also need to be modified from the aspect of observing time, observer's age and negative contrast (target luminance than the background brightness) and so on.

There comes the conclusion that the visibility level is determined by the following factors: the brightness of the target L_t, the nearby background brightness L_b and luminance threshold difference ΔL, under the same background. This paper focuses on the contrast threshold of tunnel lighting.

CONTRAST THRESHOLD SIMULTION MODELLING EXPERIMENT

The experiment is carried out in the dark and controlled by a computer program: the computer monitor's power is supplied via electronic exchange regulator; the background brightness of the screen is stable and easy to adjust; the target is the ring Ron Doyle on the screen, whose brightness is controlled by the conductor through the computer program, which makes the positive and negative contrast visual experiment more easy; experimental perspective is 7.45', which is determined by the distance between the conductor and screen, as well as the size of Ron Doyle ring; the target is presented for two seconds; under the conditions of positive and negative contrast conditions, conduct the experiments which include the probability of identifying different object and different backgrounds brightness to 20 subjects.

Probability of identification

We know that in different conditions, the probability is different for human eyes identify the target within a short period of time (long-range identification probability tends to be100%. To achieve the same identify probability, the better the lighting conditions is, the less time it required, namely to identify the target in a shorter time.

According to professor Zhang Qingxuan's book Architectural Lighting Environment, the formula of identify probability is shown as following formula (3)[13]:

$$P = \frac{n_T - (n \times \frac{1}{k})}{n - (n \times \frac{1}{k})} \times 100\% \quad (3)$$

Where: P - identify probability;

n - The total frequency of occurrence of the target;

n_r - The number of correct answers;

k - Number of the opening direction of the target.

In this study, a computer program automatically recorded a variety of experimental results under the different identify probability and selected to analysis the data when P = 55.6% (the different identify probabilities are shown in TABLE (1).

TABLE 1: Identification probability

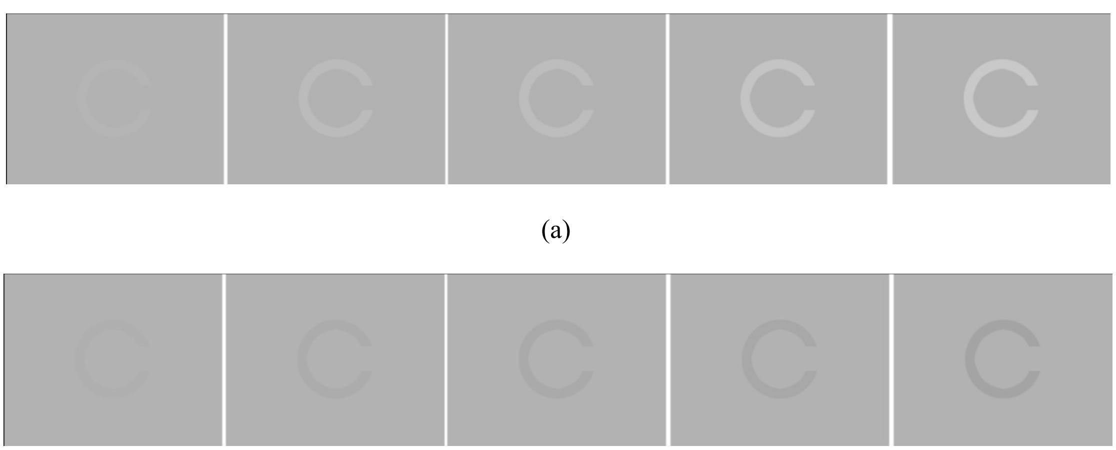
Correct number of time	3	4	5	6	7	8	9	10	11	12
Number of presenting the target	12	12	12	12	12	12	12	12	12	12
Identification probability	0.0%	11.1%	22.2%	33.3%	44.4%	55.6%	66.7%	77.8%	88.9%	100%

Background brightness simulation

To start the experiment, the background brightness of the computer screen shall be classified and adjusted within the range of road and tunnel lighting. Background luminance levels are divided into six levels, according to the number of relations, namely $10^{-1.5}$cd/m^2, 10^{-1}cd/m^2, $10^{-0.5}$cd/m^2, 10^{0}cd/m^2, $10^{0.5}$cd/m^2 and 10^{1}cd/m^2; the target luminance is 0.03162cd/m^2, 0.1000cd/m^2, 0.3162cd/m^2, 1.0000cd/m^2, 3.1620cd/m^2 and 10.0000cd/m^2. Because the computer program adopts the gradation from 0 to 255 in adjusting the screen brightness, the brightness cannot be adjusted fully strictly to the logarithmic relationship. Thus, the experimental background brightness, measured by luminance meter BM-5, is 0.0317cd/m^2, 0.1176cd/m^2, 0.3515cd/m^2, 1.074cd/m^2, 4.070cd/m^2 and 11.67cd/m^2[14,15].

Simulation experiment procedure

First, make the observer adapt to the visual environment of the dark room and familiar with the testing process as well as the required operation. The formal experiment begins after two to three round of pre-observation. When the formal experiment begins, the conductor adjust the background brightness to the required level, and in accordance with the requirements of positive contrast, slowly adjust the brightness of the target (Ron Doyle ring brightness) to a level that the target is slightly brighter than the screen background in Figure (1). Then make the observers judged when the target can just be seen (i.e.: threshold condition). Roughly determine the observer's contrast threshold in this luminance, the conductor the motioned observer to start the experiment. Because the observer's different, the measurement shows that the time of correctly judging the opening direction of Long Doyle ring are different, arranged from 6 to 10, which means the identify probability ranged from 33.33% to 77.8%. During the test, conductor only records the data that each observer can identify at least three times under each identify probability. After finishing a set of experiment under the same background brightness, the conductor will turn the screen background brightness to the next level, repeating the experiment until finishing all the pre-settled background brightness. Then, follow the same steps. Start the negative contrast experiment, the conductor adjusts the target darker than the screen background. Finally, make a comparative analysis of the two group data.



(a)

(b)

(a) positive contrast, (b) negative contrast;
Figure 1 : Contrast of Ron Doyle ring.

Data analysis and guidance

In the positive and negative contrast conditions, the angle α=7.45', target presentation time t=2s, identification probability P=55.56%, calculate average record of human eye contrast threshold in different background luminance L_b. and then follow the formula (2), calculate the difference between the target and background brightness, as well as luminance contrast C, which can find that there is a high relevant between L_b and C, see TABLE 2 and Figure (2).

TABLE 2 : Experiment on the value of the measured data

Background	Positive contrast	Negative Contrast
Log L_b	Log C	Log C
-1.4996	-0.2178	-0.3024
-0.9296	-0.5506	-0.6505
-0.4541	-0.7931	-0.8898
0.0310	-1.0146	-1.0883
0.6096	-1.2254	-1.2626
1.0671	-1.3357	-1.3526

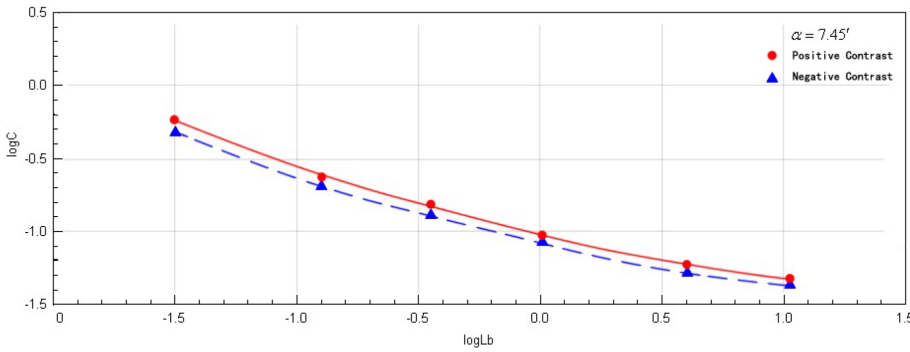


Figure 2 : The contrast logarithmic relation between C and L_b in the same identify probability.

RESULT AND DISSCUSS

In the dark background luminance environment, contrast plays an important role in visual target identification process; with the increase of the brightness of the background, the contrast needed to identify the target is reducing (more gentle curve), that is, when the background brightness increases to a certain extent (such as bright visual state), the contrast's influence on identify probability is decreasing, whereas the other factor's effects increased, such as object size, fixation duration;

When the brightness of the background is the same, the value of the negative contrast is lower than that of positive contrast; when the contrast is the same, the background brightness required by negative contrast is lower than that of the positive contrast.

Contrast degree plays an important role in identifying small target in tunnel illumination. Thus, raising the contrast degree can improve the target's visibility, which can create a safer tunnel environment;

In the same lighting conditions, when the brightness of target and background's absolute difference are the same, dark target can be identified easier than brighter one, see Figure (3); in the same identification conditions, when the brightness of target and background's absolute difference are the same, the background brightness required by identifying dark target is lower.

Figure 3 : In road or tunnel lighting environment, the small target of the negative contrast is easy to be indented than positive contrast

CONCLUSIONS

Comparing to road and tunnel lighting index such as: illuminance, luminance or uniformity, the visibility is a new design parameter, which indicate the difficulty in identify the small target in a certain environment. Increasing the contrast can increase the small target's visibility so as to create a better condition for safety.

The contrast threshold shows that when the absolute value of the difference between the target brightness and background brightness are the same, in the same lighting conditions, the dark object is easier to be identified than the brighter one. In the same identifying condition, the dark object required lower bright to be identified.

Improving the tunnel lighting in the aspect of light distribution can improve the brightness of the background and reduce the target luminance, forming small target negative contrast lighting environment and enhancing the lighting visual effect, without increasing the energy consumption, which as a whole lays the basement for tunnel lighting energy saving

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