Research on lamp distribution parameters of interior zone of high altitude highway tunnel based on lighting energy saving

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Abstract: According to the lighting energy-saving standards of plateau tunnels, the optimal lighting parameters in the middle segment of the highway tunnel is investigated under the conditions of plateau environment. With the minimum total power consumption as the target and the tunnel driving safety as the basic conditions, this article sets up parameter models of centerline layout, centerline sideways, symmetrical sides, and staggered sides in total 4 styles of distribution lights in tunnel interior zone. It is divided into different groups, each of which simulates 15 sets of parameters with different lamp spacing and compares the average luminance of different lamp forms and spacing conditions. The results show that: under the same spacing, the luminance of staggered sides arrangement is the highest, and the effect of centerline sideways is the worst. With the increase of the altitude, the safe lamp spacing decreases. The spacing of distribution lights in the middle section of the tunnel with the altitude of 2000m, 3000m, 4000m and 5000m is 47.5m, 42.5m, 37.5m and 35m respectively.

1. Introduction
With the vigorous development of China's transportation industry, the mileage of highways in China keeps increasing, and highway tunnels continue to extend to the high-altitude mountains in the west. In the western part of Sichuan province, especially in the western Sichuan plateau region, the number of high-altitude road tunnels has increased dramatically. According to relevant statistics [1-3], there are about 884 highway tunnels in Sichuan province, with a total length of 1100.366km. The operational cost of the highway tunnel lighting facilities accounts for a large part of the highway operation, and the illumination in the middle segment of the tunnel, which accounts for the largest proportion and consumes the most energy, is worthy of attention. Therefore, a decrease of the lighting energy consumption of the middle segment of the tunnel will greatly reduce the total energy consumption of the tunnel lighting. China's current lighting specification Guidelines for Design of Lighting of Highway Tunnel (JTG/T D70/2-01-2014) [4] according to different design speed and traffic volume, the luminance value, illuminance value and luminance uniformity of each lighting section of the tunnel are stipulated, and four types of luminaries' arrangement forms are put forward, such as centerline layout, centerline sideways, symmetrical sides, and staggered sides.

Angel Pachamanov [5] established an optimization model for the energy saving problem of tunnel lighting, and obtained the optimal lighting parameters of fixed lamp power. Jim Degnan [6] made a detailed analysis on the theory of highway tunnel lighting and the selection of highway tunnel light source, which reduced the demand for tunnel brightness and had obvious energy-saving effect. Wang Shaofei, Tu Yun [7] and others put forward 15 important measures for energy saving of highway tunnel lighting according to the different lighting energy saving requirements of new highway tunnels and
operating highway tunnels, and put forward the application schemes of these energy saving measures. Du Chao, Yi Yingkuan et al. [8] proposed a new method based on the intelligent lighting dimming control algorithm to effectively solve the problem of lamp damage and unsuitable light environment caused by improper control methods in tunnel lighting in high altitude areas of the plateau. Tian Nuoyu, Ting Wei [9] proposed a scientific and reasonable control scheme design and practical application scheme for the design and application of intelligent lighting control schemes for extra-long tunnels. Li Ning, Wang Xiaodong et al. [10] established the intelligent optimization model of tunnel lighting based on genetic algorithm with minimum energy consumption of the lighting system as the objective function of operation. Researchers from Chongqing transportation research and design institute applied "mesopic vision theory" and "visual effect method of response time to target objects" to the research on highway tunnel lighting [11], providing design parameters for the application of new energy-saving light sources such as LED lights in highway tunnels. Liu Xingmao, Lan Yu et al. [12] carried out a simulation analysis of the installation height and spacing of the tunnel lighting fixtures, and obtained the optimal installation spacing and height of the lighting system in the tunnel.

At present, the research on the energy saving of tunnel lighting mainly focuses on the control of the lighting system, while most of the research on the parameter optimization of tunnel lighting distribution lamp only considers the highway tunnel in the general low-altitude area, and the research on the energy saving of highway tunnel lighting in the plateau environment is less. Most of the tunnels are designed by the tunnel lighting designer according to the design speed and specific traffic volume of the tunnel. In the actual project, the designer's experience is often used as a reference, and the maximum utilization of the lighting light of the tunnel luminaire is not fully considered, which reduces the utilization rate of the luminaire and causes the phenomenon of insufficient or excessive lighting of the actual road surface.

In this paper, under the climatic conditions of the western Sichuan plateau and meeting the driving safety conditions, a tunnel model is established by a simulation software called DIALux to study the tunnel lighting effects of the lamps and lanterns in tunnel interior zone of the western Sichuan plateau under different combinations of spacing and layout forms. The optimal lighting parameters of the middle segment of the lighting will greatly decrease the lighting energy consumption of the middle segment of the western Sichuan plateau tunnel to reduce operating costs and improve economic and social benefits.

2. Technology index of luminaire distribution for tunnel interior zone
   (1) Luminance
   According to the research route, the method of combining automobile headlights lighting and tunnel lighting is adopted. The recommended luminance for interior zone of plateau highway tunnel is taken as the standard. The value which reduces the luminance of automobile headlights is regarded as the design value of the energy-saving lighting of high-altitude highway tunnel. The Lighting design standard for interior zone of high-altitude highway tunnel is shown in Table 1:

   | Altitude(m) | 2000  | 3000  | 4000  | 5000  |
   |------------|-------|-------|-------|-------|
   | Recommended luminance (cd/m²) | 0.73  | 0.82  | 0.91  | 1.0   |

(2) Flicker frequency
   The strobeflash in the tunnel will make the driver's vision uncomfortable or be more seriously affected, and there will be dizziness and irritability, which will cause visual errors and affect traffic safety. The stroboscopic effect in the tunnel includes the flicker of the light from luminaire, as well as the flicker formed by the reflection of the luminaire on the surface of the object. The light emitted by the discontinuously arranged luminaires will alternately change light and dark, which will stimulate the human eye to produce visual discomfort.

   According to Guidelines for Design of Lighting of Highway Tunnel (JTG/T D70/2-01-2014): When the driving time at the designed driving speed in the tunnel exceeds 20 seconds, the layout spacing of lamps and lanterns should meet the requirement that the flicker frequency is below 2.5Hz
or above 15Hz (the flicker frequency is the ratio of the designed driving speed to the spacing of lamps and lanterns. For example, the Balangshan Tunnel, the western Sichuan plateau highway tunnel, which has a designed driving speed of 40km/h is calculated that the spacing of the lamps must be less than 2.67m or greater than 16m.

3. Analogue simulation for tunnel lighting environment

A tunnel model with a clear width of 9.8m and a clear height of 7.05m was established in DIALux. The specific model diagram is shown in Figure 1. The lighting effect of the tunnel interior zone under four conditions of installation of lamps in the central line of the vault, 1.0m to the right of the central line of the vault, symmetrical on both sides, and staggered on both sides \cite{13} was respectively studied, in which the height of the lamps in the form of lamps on both sides was 5.2m. The traffic mode was a two-lane, two-way traffic design with a speed of 40km/h, a road surface reflection coefficient of 0.27, a tunnel side wall reflection coefficient of 0.58, a tunnel vault reflection coefficient of 0.1, and a model tunnel length of 500m. The 60 groups of conditions with 15 types of lighting spacing (15m, 17.5m, 20m, 22.5m, 25m, 27.5m, 30m, 32.5m, 35m, 37.5m, 40m, 42.5m, 45m, 47.5m, 50m) and 4 types of lighting layout (centerline layout, centerline sideways, symmetrical sides, and staggered sides) were calculated. The selected lamp model was Yaming ZQ617a-LED060HT-5700M1/220, LED light source, the rated power was 60w, and total luminous flux was 6000lm \cite{14,15}.

4. Numerical simulation results

The DIALux software was used to simulate four types of lamp layouts: centerline layout, centerline sideways, symmetrical sides, and staggered sides. There are a total of 60 types of lamp spacing from 15m to 50m. Through the analysis of the pseudo-color map, the overall effect of the two sides of the lamp is better than that of the single-line lamp (centerline layout and centerline sideways), and the symmetrical sides is better than the staggered sides. The relationship between the lamp layout, spacing and average luminance can be obtained, as shown in Figure 2:
5. Conclusions

Through this study, the following main conclusions are drawn:

(1) In the interior zone of highway tunnel on the west Sichuan plateau, the best lamp distribution is staggered sides, symmetrical sides is better, followed by the centerline layout, and the worst layout effect is the centerline sideways.

(2) With the increase of altitude, the safe lamp spacing decreases, and the spacing of distribution lights in interior zone of highway tunnel with the altitude of 2000m, 3000m, 4000m and 5000m is 47.5m, 42.5m, 37.5m and 35m respectively.

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