Exploration of Highway Fair and Vertical Curve Index Considering Night Parking Visual Distance

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ABSTRACT

The safety of night driving is far lower than that of daytime driving. Considering the route index only, one important reason is that the control of route index does not consider the requirement of night parking sight distance. According to the scattering angle, headlight height and elevation angle of vehicle headlights, this paper calculates the relevant parameters of night parking sight distance for highway designers. The research results show that the minimum horizontal and vertical curve radius satisfying the night parking sight distance of automobiles is larger than the minimum radius required by Highway Route Design Code, and in some cases even larger than the general minimum radius required by Highway Route Design Code. The reference range of parameters is given.

KEYWORDS: highway engineering; night stopping sight distance; radius of plane curve; radius of vertical curve

INTRODUCTION

Parking sight distance is one of the important guarantees for safe driving of automobiles and the main basis for geometric design of highways. When a car is driving on the highway, if it encounters obstacles in front of it, and it is impossible to drive into the adjacent lane to avoid it, only take braking measures to make the car stop completely in front of the obstacles in order to ensure safety. The shortest distance that must be guaranteed is called parking sight distance. When formulating the minimum radius of horizontal and vertical curves, China's Highway Route Design Code (hereinafter referred to as the "Code") mainly considers the condition of vehicles running in the daytime, but not at night.

According to the survey, the traffic accident rate at night and the harm of traffic accident at night are much higher than that at daytime. In the United States, traffic accidents account for 54% of the total in one dark day and night, with a mortality rate of 55.8%. The number of deaths in 100 million kilometers of driving is 1.5-2 times higher at night than during the day. Traffic accident statistics show that the ratio of traffic accidents between daytime and night is 1:1.87. There are many reasons why the accident rate of motor vehicle drivers at night is higher than that in daytime. One of the important reasons is that some horizontal and vertical curve radius satisfying the requirements of the Code can meet the requirements of parking sight distance in daytime, but at night, due to the influence of the scattering angle, height and elevation angle of the headlamp, the accident occurs because the night parking sight distance can not meet the requirements.

Based on the scattering angle, height and elevation angle of the headlight, this paper calculates the relevant parameters of the night parking sight distance, and gives the reference values of the horizontal and vertical curves considering the night parking sight distance for the reference of highway designers.

RADIUS OF PLANE CURVE

The minimum radius of circular curve stipulated in the Code is determined by the conditions required for a car to travel safely and comfortably in the curve part. The essence of the minimum radius of a circular curve is that the lateral force generated by a vehicle driving
on the curve part of a highway does not exceed the allowable limit of the friction between
the tire and the road surface, which can be calculated by the following formula:
\[
R_{\text{min}} = \frac{v^2}{127(1+\mu)}
\]  

(1)

\( R \) is the radius of the circular curve, \( V \) is the speed of the vehicle, \( \mu \) is the transverse
force coefficient and \( I \) is the transverse slope of the road. However, this formula only
considers the mechanical requirements of safe driving, but does not consider the requirements
of safe driving at night.

According to the survey, the driver's Horizon Field of vision decreases with the
increase of vehicle speed. The relationship between Horizon Field of vision and vehicle speed
is shown in Table 1.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>95</th>
<th>105</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal field of vision (°)</td>
<td>90-100</td>
<td>75</td>
<td>60</td>
<td>40</td>
<td>&lt;40</td>
</tr>
</tbody>
</table>

When driving at night, the driver's horizontal field of vision is limited by the horizontal
scattering angle of the headlamp. As shown in Figure 1.

\[
S = R \times \frac{\pi \alpha}{180}
\]  

(2)

Among them, \( S \) is the parking sight distance, \( R \) is the radius of the vehicle trajectory,
and \( \alpha \) is the headlamp to calculate the horizontal scattering angle.

With regard to the calculation of scattering angle of headlamps, the United States
stipulates 24 degrees and ECE stipulates 10 degrees. At present, there are no specific
provisions in China. According to the test analysis, the minimum illumination required
for safe driving at night is about 1.5Lx. When illuminating with automobile headlights, the
stronger the light, the better the distance and the more uniform the illumination should
be provided within the illumination area. The ideal high-light lamp should have the maximum
luminous intensity in the central part of the beam and throw out a rectangular beam. Through
the investigation of the light distribution performance of automobile headlamps, it is found
that the parabolic or quasi-parabolic reflectors are almost all used in the headlamps at present,
and patterns are made on the reflector or the glass cover of the reflector. These patterns are
used to deflect the light inside the headlamps, so as to maximize the light intensity at the
center of the headlights and to project approximately rectangular beams. The beam is emitted
at an angle of approximately 10-20 degrees. Although there is light scattering outside the cone
angle, the light intensity is relatively weak, which can not be considered based on the angle of driving safety.

Documents show that the visibility of the luminous surface of a high-light lamp (including the visibility of the non-luminous area which appears from the observation direction) must be guaranteed in the diffusion area formed by the buses on the perimeter of the high-light lamp. The angle between the area and the headlamp reference axis should not be less than 5 degrees, that is to say, the scattering angle calculated by the headlamp should be more than 10 degrees.

Considering the visibility of the luminous surface of the high-light lamp and the shading angle of the anti-glare facility, and referring to the value of the scattering angle calculated by the headlamp abroad, this paper calculates the scattering angle by taking the headlamp as 15 degrees, i.e. the horizontal visual angle of the driver is 15 degrees when driving at night. The minimum radius of the circular curve of the horizontal scattering angle of the automobile headlamp is taken into account when the formula is substituted with a=15 degrees (as shown in Table 2):

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>120</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>30</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopping sight distance (m)</td>
<td>210</td>
<td>160</td>
<td>110</td>
<td>75</td>
<td>40</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>General Minimum Radius Required in the Code (m)</td>
<td>1000</td>
<td>700</td>
<td>400</td>
<td>200</td>
<td>100</td>
<td>65</td>
<td>30</td>
</tr>
<tr>
<td>Minimum Radius of Limit Required in Code (m)</td>
<td>650</td>
<td>400</td>
<td>250</td>
<td>125</td>
<td>60</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Minimum Half of Horizontal Scattering Angle of Automobile Headlights (m)</td>
<td>800</td>
<td>610</td>
<td>420</td>
<td>290</td>
<td>155</td>
<td>115</td>
<td>75</td>
</tr>
</tbody>
</table>

From Table 2, it can be seen that the minimum radius of the circular curve considering the horizontal scattering angle of the headlamp is larger than the minimum radius required by the Code. When the design speed is less than 80 km/h, the minimum radius of the circular curve considering the horizontal scattering angle of the headlamp is even greater than the general minimum radius required by the specifications, and the lower the speed, the more serious the situation is.

RADIUS OF CONVEX VERTICAL CURVE

When determining the minimum radius of vertical curve, the Code mainly considers three factors: mitigation of impact, short driving time and meeting the requirements of visual distance. When calculating the minimum radius of convex vertical curve, the three factors play a controlling role in the visual distance requirement, and the effective control is that the length of convex vertical curve is longer than the visual distance S, as shown in Figure 2.
Figure 2: Radius of Convex Vertical Curve Considering Front Vehicle Height

The relevant parameters can be obtained from the above figure:

\[ h_1 = \frac{d_1^2}{2R} \]  \hspace{1cm} (3)

\[ h_2 = \frac{d_2^2}{2R} \]  \hspace{1cm} (4)

then:

\[ S = d_1 + d_2 = \sqrt{2R(\sqrt{h_1} + \sqrt{h_2})} \]  \hspace{1cm} (5)

\[ R_{\text{min}} = \frac{S^2}{2(\sqrt{h_1} + \sqrt{h_2})^2} \]  \hspace{1cm} (6)

Among them, \( S \) is the parking sight distance, \( R \) is the radius of convex vertical curve, \( h_1 \) is the driver's apparent height \( h_1 = 1.2 \text{m} \), \( h_2 \) is the obstacle height \( h_2 = 0.1 \text{m} \).

In the Code, it is stipulated that the driver's line of sight is 1.2m high, and only the daytime situation is considered. Because the driver's sight at night is affected by the headlamp illumination, the headlamp height of the car is 0.75m, which is less than the driver's sight height, so the driver should take \( h_1 = 0.75 \text{m} \) at night.

By substituting \( h_1 \) and \( h_2 \) into the formula, the following table 3 can be obtained:

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>120</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>30</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopping sight distance (m)</td>
<td>210</td>
<td>160</td>
<td>110</td>
<td>75</td>
<td>40</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>

| General Minimum Radius Required in the Code (m) | 17000 | 10000 | 4500 | 2000 | 700  | 400  | 200 |
| Minimum Radius of Limit Required in Code (m) | 11000 | 6500  | 3000 | 1400 | 450  | 250  | 100 |
| Minimum Radius Considering Headlight Height of Vehicle (m) | 15750 | 9145  | 4320 | 2010 | 570  | 320  | 145 |

From Table 3, it can be seen that the minimum convex vertical curve radius considering the headlamp height is larger than the minimum radius required by the Code, which is close to the general minimum radius value.
RADIUS OF CONCAVE VERTICAL CURVE

When determining the minimum radius of concave vertical curve, two kinds of sight distance requirements should be met: the driving sight distance under the bridge and the night driving sight distance, in which night driving sight distance plays a controlling role, and the vertical curve length is longer than the sight distance $S$ as an effective control, as shown in Figure 3.

![Figure 3: Concave Curve Radius Considering Upper Elevation Angle of Lamp](image)

Then there are:

$$h + S \cdot \tan \delta = \frac{s^2}{2R} \quad (7)$$

$$R_{\text{min}} = \frac{s^2}{2(h + S \cdot \tan \delta)^2} \quad (8)$$

Among them, $S$ is parking sight distance, $R$ is concave vertical curve radius, $h$ is equal height in front of the car, $h = 0.75\text{m}$, and $\delta$ is headlamp elevation angle.

As for the headlamp elevation, according to the relevant research of vehicle lighting, the landing distance of the far-light beam center is 100m, which is equivalent to the downward inclination angle of the main optical axis of the far-light lamp about 0.5 degrees. According to the installation regulations, the angle between the visibility of the luminous surface and the reference axis of the headlamp is not less than 5 degrees (see Fig. 4). In this way, the headlamp elevation should be 4.5 degrees.

![Figure 4: Visibility of the luminous surface of a high-light lamp](image)

Far-light light scattering upward can increase the visible length. However, the automobile headlights are conical distribution, with the strongest illumination in the center of the beam and gradually weakening outward. The larger the elevation angle of the light
upward, the longer the scattering distance, the weaker the illumination intensity. Therefore, in order to ensure good illumination at night, the headlamp elevation is generally less than 2 degrees in calculation, such as 1.5 degrees in China's "Code" and 1 degree in American Association of Highway and Transportation Workers (AASHTO). With the development of expressways in western mountainous areas in China, the traffic volume at night increases rapidly. Because of the terrain limitation, the vertical curve of mountain expressway often takes the low limit value. In order to ensure the safety of driving at night, the elevation angle of headlamp is taken as 1.0 degree in the calculation. By substituting the known data into the formula, Table 4 below can be obtained.

Table 4 Concave Vertical Curve Radius Considering the Elevation Angle of Car Lamp

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>120</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>30</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopping sight distance (m)</td>
<td>210</td>
<td>160</td>
<td>110</td>
<td>75</td>
<td>40</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>General Minimum Radius Required in the Code (m)</td>
<td>6000</td>
<td>4500</td>
<td>3000</td>
<td>1500</td>
<td>700</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>Minimum Radius of Limit Required in Code (m)</td>
<td>4000</td>
<td>3000</td>
<td>2000</td>
<td>1000</td>
<td>450</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Minimum Radius Considering Vehicle Elevation Angle (m)</td>
<td>4995</td>
<td>3615</td>
<td>2265</td>
<td>1365</td>
<td>550</td>
<td>355</td>
<td>180</td>
</tr>
</tbody>
</table>

From Table 4, it can be seen that the minimum concave vertical curve radius considering the elevation angle of the headlamp is larger than the minimum radius required by the Code.

CONCLUSIONS

Considering the scattering angle, headlamp height and elevation angle of the vehicle headlamp, the relevant parameters of the night parking sight distance of the vehicle are calculated for the reference of highway designers in design work. But there are many reasons for traffic accidents at night, and the lack of sight distance is only one of them. Especially when the hilly area is restricted by the terrain, the radius of horizontal and vertical curves often adopts the minimum value stipulated in the Code, which is extremely disadvantageous to driving at night.

It should be noted that only when the curve length L is larger than the parking sight distance S, the result will be smaller when the curve length L is smaller than the parking sight distance S, so the effective control should make the curve length larger than the required distance.

REFERENCES

Yang Shaowei. Road Survey and Design [M]. 2006