Study on Driver’s Observation of Entrance while Approaching to Tunnel

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ABSTRACT

Determination of luminance at road tunnel threshold zone is critical for driver’s safety and economic standpoint. Lighting system shall be designed and controlled for the driver to identify the obstacle at tunnel threshold zone from the minimum stopping distance from the start point of threshold zone while driving at design speed or regulated speed. Farther the distance the driver can identify the obstacle at tunnel entrance the lower the luminance required for identifying the obstacle. This study as the basic study to determine the optimal luminance level at threshold zone is intended to conduct the real-car test with the subject using Eye Gaze and Head Pose Tracking System to investigate the driver’s visual characteristics (gaze and search) and analyze the result, thereby identifying the fixation point and searching pattern that have effect on driver’s visual adaptation.

Keywords: Tunnel threshold zone, fixation point, tunnel luminance.

1. INTRODUCTION

Because of topographic features in Korea, the tunnels across the nation totaled 1,456 as of 2011 and electricity cost for tunnel lighting reached as much as W34.6bil, accounting for 60% of the total tunnel maintenance cost, which implies that determination of luminance at tunnel threshold zone where considerable amount of electricity and lighting facilities at tunnel section are concentrated is very important in terms of safety and cost efficiency. Tunnel threshold zone is defined as tunnel entrance or the zone from entrance shadow line to stopping distance toward tunnel center and tunnel entrance lighting shall be designed and controlled for the driver to identify the obstacle at tunnel threshold zone from the minimum stopping distance from the start point of threshold zone (Control Point) while driving at design speed or regulated speed.

Farther the distance from fixation point at same luminance condition for the driver, in other word, farther the distance the driver starts gazing the tunnel entrance the lower the luminance required for identifying the obstacle. This means, driver’s eye at fixation point or more accurately, fovea tends to be adaptable more quickly to low luminance at tunnel entrance than outdoor environment so as to be easily able to identify the obstacle at tunnel threshold zone. In this study, as the basic research to determine the optimal luminance level at tunnel threshold zone, a real-vehicle test with 8 subjects was conducted using eye gaze tracking system and global positioning system (GPS) and analysis by comparing travel time from a certain point to tunnel entrance with the time of gazing (Gaze concentration rate) at tunnel entrance using S/W for driver’s visual pattern analysis and consequently, fixation point on which the drivers concentrate their eye was proposed.

2. LITERATURE REVIEW

Tunnel, depending on function, is divided into access zone, threshold zone, transition zone, interior zone and exit and the luminance is different by zone. (Fig 1)

In access zone, the driver who is approaching to the tunnel entrance can see inside the tunnel which is defined as the distance from the control point (point distanced from the tunnel entrance by stopping distance) Threshold zone refers to the zone from tunnel entrance or entrance shadow line to stopping distance toward the tunnel center and the total distance of threshold zone shall be equal to or longer than stopping distance. Threshold zone luminance (Lth) in this study refers to mean luminance at certain point in threshold zone. Viewing luminance level by zone, luminance varied rapidly at the transition area between access zone and threshold zone.

Thus the driver who is not adaptable to the luminance in threshold zone suffers black hole and is not able to identify the road condition at tunnel entrance.
determining the luminance level in threshold zone, determines the luminance in threshold zone corresponding to proposed standard after estimating the adaptation luminance.

Adaptation luminance is estimated using mean luminance ($L_{20}$) within driver’s $2 \times 10^\circ$ conical field of view. Estimate method is classified into the method using standard chart and the method using field value.

The study by Narisada (1972, 1974, 1975) on fixation point and variation of tunnel entrance scale is highlighted as follows.

The driver approaches toward the tunnel without information on obstacle in tunnel and tends to be cautious when reaching to the certain distance. The point where the drivers start focusing their eye is called fixation point.

The longer the fixation point at same outdoor luminance, in other word, the farther the distance the driver starts focusing eyes the lower the luminance required to identify the obstacle in threshold zone.

The Fig 2 shows the relation between luminance level at tunnel entrance to recognize the obstacle and elapsed time since the subject starts focusing on tunnel entrance and the farther the point where the subject starts focusing the lower the luminance level in tunnel required to recognize the obstacle.

![Figure 2: Results obtained by the simulator experiments as the relationship between luminance to be perceived in tunnel and time elapsed when observer begins to concentrate his attention on tunnel entrance. (K. Narisada, 1975)](image)

Visual adaptation of the subject in test to determine the luminance for certain outdoor luminance shall be set to become equivalent to visual adaptation state when reaching to certain point.

- Luminance measured by luminance meter at specific point is the value distributed on driver’s view at specific point without including luminance history (measured luminance has no relationship with visual adaptation state at specific point)
- Human’s visual adaptation state is determined by adaptation history and adaptation history is determined by luminance history.

- Driver’s field of visual while driving keeps changing and visual system keeps undergoing adaptation process and adaptation level keeps changing.
- When initial luminance is very high or luminance varies rapidly, adaptation lag occurs and thus, it cannot be said for sure that driver has become adapted to the luminance at present position.
- Driver’s visual adaptation is affected by operation behavioral factors such as driver’s gaze pattern and the luminance at tunnel entrance and in tunnel and obstacle.
- Thus model test shall be designed to simulate the luminance history experienced by the driver till specific point similar to real condition so as to express the driver’s visual adaptation at specific point as accurate as possible.
- Should model test fail to satisfy above conditions, model test result cannot be reflected in lighting design for threshold zone.
- When luminance history experienced by the driver and the subject is different even though the luminance measured at control point in tunnel and the luminance identified from model test are equal numerically, it’s because of the difference in visual adaptation state or the ability to recognize the obstacle and $L_1$ in model test shall not be considered the adaptation luminance ($L_a$)
- The driver starts becoming adaptable to tunnel entrance from the time to start gazing the entrance and tunnel entrance becomes look larger and driver’s adaptation becomes greater and thus fixation point is critical in determining the adaptation luminance.

Schreuder (1964) demonstrated various combinations of luminance ratio and luminance contrast using a model simulating the tunnel entrance within $20^\circ$ conical field of view from control point and identified whether the subject recognized the obstacle at threshold zone from control point. Schreuder’s test was based on following three assumptions regarding tunnel access, test environment and driver’s visual adaptation.

First, driver’s eyes at access zone constantly and stably became adaptable to mean luminance at the center.

Second, driver’s visual adaptation while driving the access zone was equivalent to the subject’s eyes which were completely adapted to uniform luminance at standard field in test condition. Third, driver’s visual adaptation did not vary significantly till getting closer to tunnel entrance.

But Narisada(1972, 1975) asserted that though the luminance in standard view assumed at test condition by Schreuder(1964) and luminance measured at the field is considered the same, assertion that adaptation by driver’s eyes assumed at the test and adaptation in tunnel
are equal is not correct because of relatively darker and tunnel entrance which looks larger as approaching to the tunnel and also the assumption that adaptation by driver’s eyes remained unchanged till the driver is getting closer to the tunnel is not correct. Narisada and Yoshikawa (1974) concluded that fixation point is about 150-200m and 82% of the drivers start focusing from 150m at least through the test for change in viewing line of driver approaching to the access zone (Fig 3).

Since then, simulator test based on study by Narisada and yoshikawa (1974) was conducted and the result has served the base of tunnel lighting standard in Japan (Fig 4).

3. METHODOLOGY

3.1 Experiment Summary
Verification experiment of driver’s visual pattern (fixation point and exploration behavior) that has effect on driver’s visual adaptation was conducted. In this study, investigation of driver’s visual characteristics (gaze and observation) through the real vehicle test of the subjects was carried out using Eye Gaze and Head Pose Tracking System and based on analysis of the result, fixation point and observation pattern that may have effect on driver’s visual adaptation were identified.

3.2 Experiment Method
The experiment was conducted at Namgochang IC ~ Bukgwangju IC on Gochang~Damyang highway (speed limit 100km.h) A round-trip distance was 52km with 12 tunnels.(Fig 5)

![Figure 3: Cumulative frequency distribution of fixation point (Narisada and yoshikawa, 1974)](image)
![Figure 4: Experiment to determine tunnel luminance level by incorporating fixation point (Narisada and yoshikawa, 1974)](image)
![Figure 5: Experiment site characteristics of tunnel entrance are as Table 1 and Table 2)](image)

<table>
<thead>
<tr>
<th>Table 1: Tunnel entrance (Namgochang IC→Bukgwangju IC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
</tr>
<tr>
<td>Tunnel</td>
</tr>
<tr>
<td>Gochang(A)</td>
</tr>
<tr>
<td>Moonsusan(B)</td>
</tr>
<tr>
<td>Jangsung 1(C)</td>
</tr>
<tr>
<td>Jangsung 2(D)</td>
</tr>
<tr>
<td>Jangsung 3(E)</td>
</tr>
<tr>
<td>Jangsung 4(F)</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>
Table 2: Tunnel entrance (Bukgwangju IC ~ Namgochang IC)

<table>
<thead>
<tr>
<th>Direction</th>
<th>jangsung 4(G)</th>
<th>jangsung 3(H)</th>
<th>jangsung 2(I)*</th>
<th>jangsung 1(J)</th>
<th>moonsusan(K)</th>
<th>gochang(L)</th>
<th>average</th>
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</thead>
<tbody>
<tr>
<td>d1</td>
<td>417</td>
<td>437</td>
<td>127</td>
<td>404</td>
<td>478</td>
<td>503</td>
<td>394</td>
</tr>
<tr>
<td>d2</td>
<td>269</td>
<td>238</td>
<td>127</td>
<td>252</td>
<td>387</td>
<td>503</td>
<td>296</td>
</tr>
<tr>
<td>d3</td>
<td>63</td>
<td>238</td>
<td>127</td>
<td>137</td>
<td>290</td>
<td>503</td>
<td>226</td>
</tr>
</tbody>
</table>

Note) d1 : When tunnel entrance becomes visible (m)
      d2 : When whole tunnel entrance becomes visible (m)
      d3 : When tunnel entrance becomes visible in front of view field (m)
      * : When the point where whole tunnel entrance become visible is 155m or less from the tunnel entrance

In this experiment, investigation of driver’s fixation point and view movement (observation) when approaching to the tunnel using Swedish Smarteye’s Smarteye Pro (SEP) which is the Eye Gaze and Head Pose Tracking System.

SEP comprises 3 eyeball camera (Pupil size, view direction and head position) and 1 scene camera and operation system.

The scene ahead of the subject was recorded by scene camera and video, changes in subject’s viewpoint & direction and head position were synchronized for analysis. SEP is able to trace again without adjustment when normal condition is satisfied even in case of failure of tracing the subject due to deviated position.

SEP is able to gather and analyze the image and data at 60Hz (60 images and data per second) based on exponator 7, but as it doesn’t provide driver’s view change and synchronized location information, separate location information gathering system is needed.

Thus, KICT’s Arseo vehicle equipped with GPS and DMI was used after interlocking with SEP (Fig 6).

Figure 6: Araseo vehicle (KICT)

Figure 7: SEP, GPS, DMI interlocking system

Driving test with 7 drivers more than 10 years of driving experience was conducted using Araseo vehicle equipped with SEP on a 52km-long with 12 tunnels Namgochang IC ~ Bukgwangju IC on Gochang–Damyang highway. The subjects drove the vehicle freely at 90~120km/h without information on test objective (Fig 7).
4. RESULTS OF EXPERIMENT

Based on data collected, driver’s observation pattern and characteristic of gazing at access zone were analyzed.

4.1 Driver’s Observation

As a result of analyzing and comparing driver’s field of view and concentration at normal zone, access zone and in tunnel, the Fig 9 shows as follows.

Driver’s field of view from normal zone till the point where the parts of tunnel becomes visible (driver starts recognizing the tunnel) shall include the sky, surroundings along the road and road surface. A field of view was relatively wider than other zones but concentration at center of the view center was generally lower. But at the point where part of tunnel becomes visible, view concentration became higher than other zones.

A field of view from the point where tunnel entrance becomes visible till ahead of tunnel entrance became narrower than previous zones and it includes tunnel entrance, surroundings along the road and road surface.

Concentration at the center of view was very high and was concentrated on tunnel entrance.

A field of view and concentration after entering the tunnel (tunnel zone and immediately before tunnel exit) were similar with previous zones and it includes road surface, wall surface and tunnel exit.
4.2 Characteristics of Gazing at Tunnel Access

Tunnel entrance was set as Region of Interest (RoI) by applying S/W for driver’s behavior analysis to driving image at access zone recorded using Scene Camera and gaze time rate(Fig 10) versus travel time required to tunnel entrance while driving to tunnel entrance was estimated as Table 3.

Fixation point in access zone by subject was based on gaze rate 70% and 80%. Fixation point estimated based on gaze rate 70% and 80% was 138m and 90m on average, respectively, and when analyzing 9 zones excluding 3 zones where the visible distance for whole...
tunnel entrance is 155m or less, average fixation point was 152m and 97m, respectively.

Table 3: Fixation Point at Tunnel Entrance

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Namgochang IC → Bukgwangju IC</th>
<th>Bukgwangju IC → Namgochang IC</th>
<th>Mean fixation point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A*</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Driver</td>
<td>Rate</td>
<td>Fixation point (m)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>70%</td>
<td>36</td>
<td>211</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>27</td>
<td>168</td>
</tr>
<tr>
<td>2</td>
<td>70%</td>
<td>42</td>
<td>236</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>33</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>70%</td>
<td>232</td>
<td>321</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>175</td>
<td>255</td>
</tr>
<tr>
<td>4</td>
<td>70%</td>
<td>278</td>
<td>418</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>236</td>
<td>321</td>
</tr>
<tr>
<td>5</td>
<td>70%</td>
<td>11</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>70%</td>
<td>169</td>
<td>183</td>
</tr>
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<td></td>
<td>80%</td>
<td>113</td>
<td>144</td>
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<tr>
<td>7</td>
<td>70%</td>
<td>169</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>83</td>
<td>355</td>
</tr>
<tr>
<td>Mean fixation point</td>
<td>70%</td>
<td>134</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>96</td>
<td>184</td>
</tr>
</tbody>
</table>

*: Zones where visible distance for whole tunnel entrance is 155m or less from tunnel entrance

5. CONCLUSIONS AND RECOMMENDATIONS

This research work, as a pilot study was aimed to determine the optimal luminance level in tunnel threshold zone, is intended to conduct the verification experiment of driver’s visual pattern which has effect on driver’s visual adaptation and obtained the result outlined as follows.

a. Visual concentration on tunnel by the driver who gazes at the sky, surroundings along the road and road surface was increased than other road facilities as is getting approached to the tunnel and the field of view is getting narrower than other zones.

b. Fixation point at tunnel entrance by the subject was 138m at gaze rate 70% and 90m at 80% in case of whole tunnel.

c. When analyzing the zones where the visible distance for whole tunnel is 155m or less, average fixation point was 152m and 97m.

On the road with design speed is 100km/h (non-passing sight distance 155m), it started gazing at tunnel entrance after non-passing sight distance, which was attributable to tunnel sign, signpost, VMS and tunnel barrier which have effect on fixation point. So, location of signpost before tunnel shall be determined considering fixation point.

According to the outcome from this study, additional consideration of fixation point in determining the luminance in tunnel threshold zone on road with design speed 100km/h or more will not be required.

As this study was conducted at limited condition, the study in various aspects considering more subjects in a wide range of age, standard test vehicle, traffic and tunnel entrance environments is needed in coming days.

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REFERENCES


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