ANALYSIS OF THE DRIVER'S BEHAVIOR AT THE ENTRANCE OF TUNNEL

KATSUHIRO IIDA, YASUO MORI
Dept. of Civil Engineering
Osaka University
2-1, Yamadaoka, Suita-shi, Osaka, 565, JAPAN

KOICHI MATSUMOTO and AKIRA HAYAMA
Research Institute
Japan Highway Public Corporation
1-4-1, Tadao, Machida-shi, Tokyo, 194 JAPAN

Abstract

In this research, we analyzed the causes of slowing down of vehicles at the entrances of tunnels, and conducted the study in order to draw up design guidelines to help plan the entrances of tunnels and thus reduce the slowing down of vehicles.

We focused on the shapes of entrances of tunnels, the alignment of the road and the positioning of road facilities at the entrances of tunnels and assumed that these have psychological effects that slow down the traffic.

INTRODUCTION

Traffic congestion on major highways has become chronic and widespread, causing many troubles in Japan. In particular, there are many tunnels where congestion occurs and traffic bottlenecks exist. Appropriate countermeasures are urgently required. For the time being, widening of roadways is the common solution to increase flow capacity and eliminate traffic jams caused by slowing of vehicle speed. ·

However, in order to cope with the anticipated increase of traffic demand as well as building of tunnels on new routes, a project is needed to study human behavioral issues and elucidate the factors affecting the actions of vehicle drivers. Past studies of tunnel factors relating to driver reactions are written in a report by Sano, Yonekawa, *et al.*, but there are few other reports in the literature.

This paper analyzes the drivers' behavioral changes against difference in the shape of tunnel opening and also changes in the driver's line of vision during reactions in order to clarify the relations between these factors. Specifically, this study investigates the reduced usage of the accelerator when going into a tunnel, increased usage of the brakes, deceleration of vehicle speed and increase of the driver's pulse rate; these were adopted as indices of individual drivers' behavioral changes. An eye mark recorder was used to trace the point of vision and thus to study the point watched by the subjects during behavioral changes.

OUTLINE OF THE EXPERIMENT

In this paper, the data mentioned above were collected through actual driving by the subjects on an expressway. As for the traffic and roadway requirements for selecting the experimental road section, the following conditions were used:
1) Scarcity of daytime traffic flow
2) Existence of various tunnel opening shapes along the route
In view of the above, the Hokuriku Expressway (round trip from Tone P.A. to Imajyo I.C. see Figure 1) was selected as the experimental road section. Furthermore, tunnels under repair and a series of short tunnels were excluded; as a result, the ten tunnels shown in Figure 2 were used for data collection in this experiment. For reference, some suggestions and the operations done at each site are shown in Figure 3.

The period of the experiment was from October 6 to October 11, 1996 and the subjects were 25 male students aged 20 to 23 years old and each of them has held a driving license for at least one year before the experiment. Each subject was asked to perform a test drive along the route the day before the experiment to minimize possible disparities in driving skill due to familiarity of this particular section.

ANALYSIS OF DRIVER'S BEHAVIORAL CHANGES UPON GOING INTO A TUNNEL

To analyze the behavior of the driver during the section from 500 meters before going into a tunnel, pulse rate, speed, and usage of accelerator and brakes were measured and classified for each of the tunnels and subjects. Figure 4 depicts the behavioral changes of a subject in the tunnel at the up section. The usage of accelerator and brakes in this context refers to the percentage indication of the respective pedal strokes from 0 (released) to 100 (fully depressed), and the pulse rate is the number of beats per minute converted from the values measured every 1/30 second.

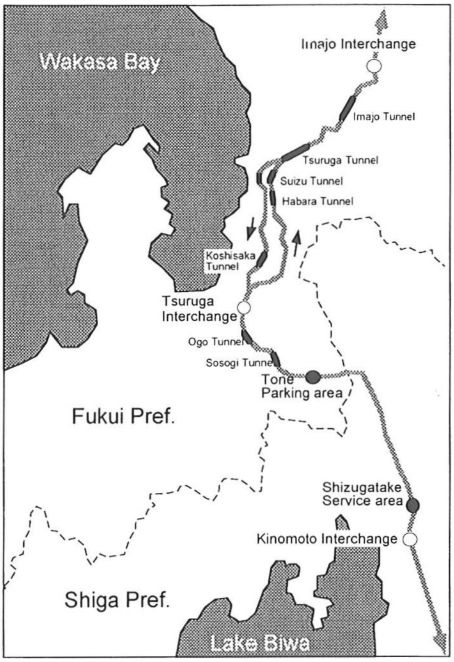

Figure 1 - Location of the Hokuriku Expressway

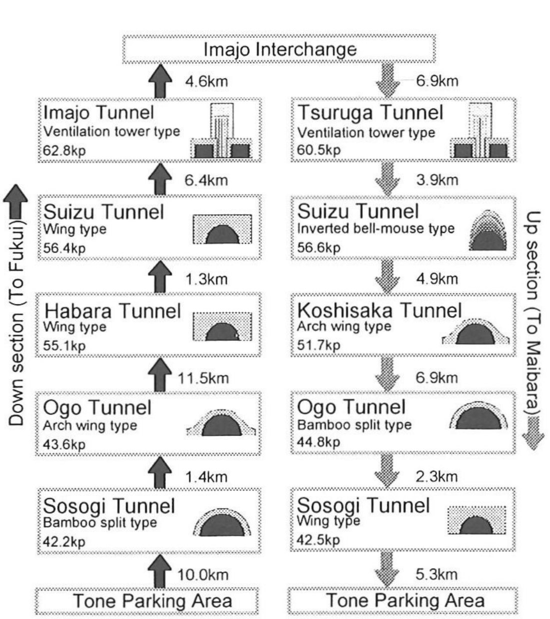

Figure 2 - Route and tunnels of the experiment

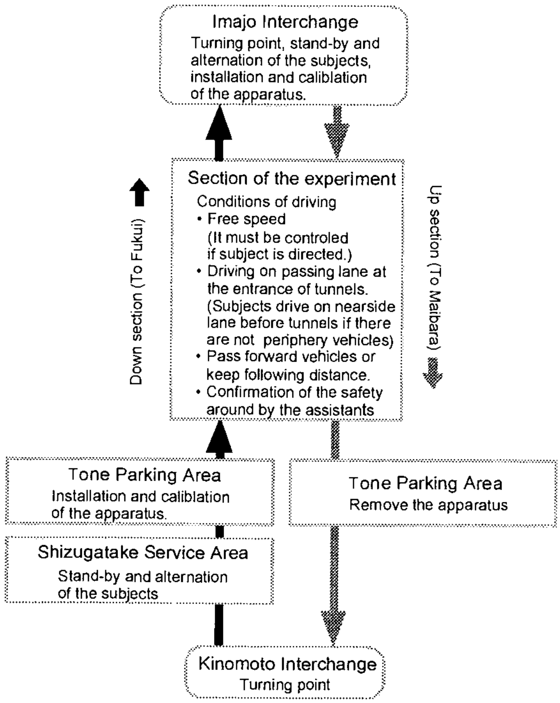

Figure 3 - Suggestions and the operations done of the experiment

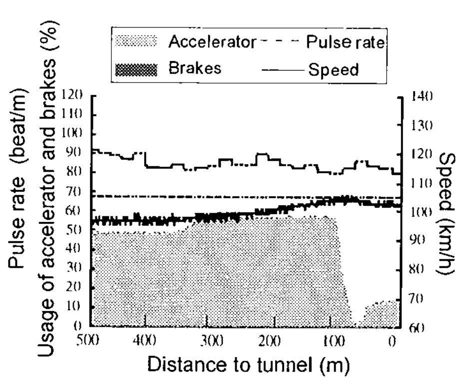

Figure 4 - Driver's behavioral changes upon going into a tunnel (example)

From these graphs, the aggregated results of subjects' behavioral changes are shown in Table 1, where "pulse rate" indicates the number of subjects who showed an increase in pulse rate and "accelerator" indicates the number of subjects who showed restraint in accelerator usage. Incidentally, operation of the brakes was found in only one case in the data, so this factor was omitted.

Difference in driver's behavioral response due to difference in shape of tunnel opening

To understand the drivers' response shown by the behavioral changes due to the difference of tunnel opening shapes, the ratio of the subjects' watching time (duration) on each element of the tunnel's approach configuration, assessed over the 500 meters before going into a tunnel, were compiled as shown in Table 2. The nomenclature of the configuration elements in this paper conforms to that of the literature (Figure. 5.)

Table 1 - Aggregated results of subjects' behavioral changes

Name	Types of tunnel openings	Pulse rate	Accelerator
Tsuruga (up)	Ventilation tower type	20	19
Suizu (up)	Inverted bell-mouse type	20	18
Koshisaka(up)	Arch wing type	20	14
Ogo (up)	Bamboo split type	22	12
Sosogi (up)	Wing type	21	19
Sosogi (down)	Bamboo split type	19	16
Ogo (down)	Arch wing type	21	18
Habara (down)	Wing type	22	15
Suizu (down)	Wing type	23	12
Imajo (down)	Ventilation tower type	20	16
Total		208	159

Table 2 - Ratio of the subjects' watching time on each elements of tunnel's approach configuration

	Ventilation tower type	Inverted bell-mouse type	Arch wing type	Bamboo split type	Wing type
Lane marking	18%	14%	16%	14%	13%
Guard rail	10%	17%	14%	9%	11%
Road surface	16%	15%	18%	22%	22%
Scene	19%	27%	23%	24%	21%
Entire tunnel opening	20%	17%	15%	15%	20%
Rest	17%	10%	14%	16%	13%

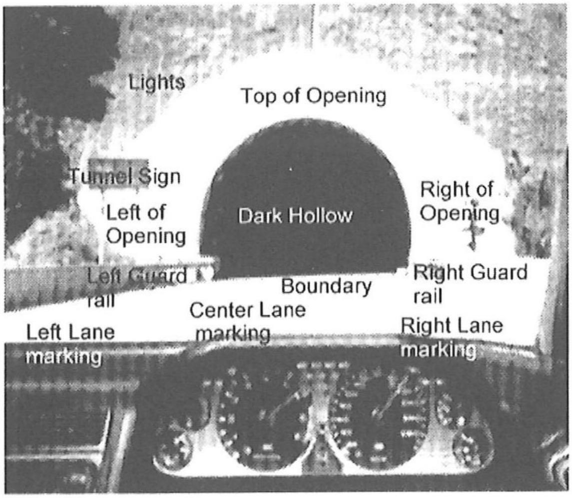

Figure 5 - Nomenclature of the configuration elements

It is evident from this table that the ratio of time while drivers were watching the entire tunnel opening (top, right, left, and dark hollow portions) is comparatively high in the case of a ventilation tower type tunnel or a wing type tunnel; by contrast, the ratio of the driver watching the entire view is comparatively low in the case of a bamboo split type tunnel or an arch wing type tunnel. A Chi-squared test conducted on this result showed a correlation between drivers' watching time and opening shape, showing significance at the 1-% level. In other words, the subject's watching time varies with the shape of the tunnel opening.

Furthermore, the ratio of watching time at each part of the opening (when the viewed object is confined to the opening only) is shown in Table 3, where the ratio refers to the accumulated time of watching the particular part of the opening divided by the total duration of watching these four parts.

Table 3 - Ratio of the subjects' watching time on each parts of the opening

	Ventilation tower type	Inverted bell-mouse type	Arch wing type	Bamboo split type	Wing type
Right	20%	20%	26%	17%	19%
Top	22%	12%	7%	10%	10%
Left	4%	9%	10%	6%	10%
Dark hollow	54%	59%	57%	67%	61%

The result shows that the time spent watching the dark hollow is longer and the time spent watching the right side of the opening is also relatively long. The ratio of the time spent watching the right side of a tunnel and the radius of curvature of tunnel opening were evaluated to obtain the correlation coefficient because the time spent watching the right side of the tunnel opening may be affected by the straightness of the road. As a result, the correlation coefficient was -0.712, showing that the smaller the radius of tunnels opening curvature, the larger the increment in the time ratio. Although statistical processing has not yet been performed, if a certain part of a tunnel is larger in area than that of other parts, such as a ventilation tower type tunnel, then the time spent watching that particular part will be much longer than that for some other types of tunnels.

Nature of points watched by subjects when behavioral changes occurred

Next, the nature of points watched by the subjects during behavioral changes such as an increase in the subject's pulse rate and reduced accelerator usage was analyzed. Table 4 shows the results of the average increase in the pulse rate classified by shape, where several increments in the same subject were taken as one sample each.

Table 4 - Results of the average increase in the pulse rate

	Ventilation tower type	Inverted bell-mouse type	Arch wing type	Bamboo split type	Wing type	Total
Lane marking	7	7	9	5	7	35
Guard rail	3	4	5	6	6	24
Right	4	5	5	3	4	21
Top	6	0	2	3	1	12
Left	1	2	3	3	3	12
Dark hollow	11	9	10	12	13	55
Rest	0	1	2	4	4	11

The results show that the most intensely watched element during the increase in pulse rate was the dark portion of a tunnel. This was presumably due to psychological influence such as uneasiness caused by the anticipated light/shade contrast and the reduced margin in darkness. As for the greatly reduced margin on the right-hand side of the tunnel opening, the area must have been watched frequently because the drivers tended to use the passing lane (right lane) during the experiment.

Other features were the high frequency of watching the top of the opening in the case of a ventilation tower type tunnel. In the present study, the top of the opening of the ventilation tower type tunnel was rectangular while the shape of other types in the same portion was semi-circular; furthermore, the area of concrete wall at the top of the opening is greater compared with those of other types. Consequently, drivers likely felt that the upper margin decreased more rapidly when entering this type of tunnel.

Change in accelerator usage immediately before entering into a tunnel

For this study, reading of the meter before the tunnel entrance at which individual subjects (drivers) started to restrain accelerator usage and quantitative analysis of the throttle displacements were conducted. Figure 6 is a scatter graph for the five tunnels in the up section, where the x-axis indicates the accelerator backing off point and the y-axis indicates the throttle displacement at the respective points. The accelerator backing off point is the distance from the tunnel opening, and the single point nearest to the tunnel opening represents a plurality of backing off points for the same driver. The throttle displacement in this context is the difference between the least accelerator stroke and before-the-change accelerator stroke divided by the before-the-change accelerator stroke.

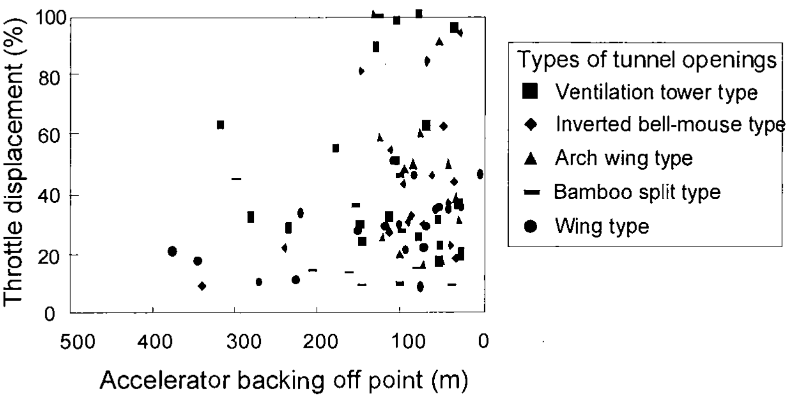

Figure 6 - Scatter graph for five tunnels in the up section

The results of analysis showed that the accelerator backing off point, on average for all the subjects, was approximately 130 meters before the tunnel entrance. Although statistical processing has not yet been completed, there was a definite correlation between the accelerator backing off point and the throttle displacement at that point.

SUMMARY AND PROBLEMS TO BE SOLVED

Behavioral changes such as the increase of pulse rate and reduced accelerator usage are generally caused by psychological impact on the driver, particularly when the driver perceives risk or tension. To analyze the point watched by the subjects during behavioral changes, showed that the dark hollow, right-hand lane mark, right-hand guard rail, and opening top of a ventilation tower type tunnel were the most frequented watched elements. As for the difference in the drivers' watching conditions due to the difference of tunnel geometry, it was shown that the greater the relative size of the opening compared to the other parts, the longer the drivers watched that specific part. For these reasons, elements that attract the drivers' attention are likely to have a psychological influence on the drivers, and thus require further examination.

In the course of elucidating the mechanism by which traffic congestion occurs, quantitatively correlated factors such as the duration of delayed traffic flow and the time required to optimize the flow rate should be the major goals of the analysis program. The development and proposal of a tunnel entrance geometry that alleviates the psychological impact on the driver must thus be addressed.

Some difficulties remain in uniformly preparing the experimental set-up in the field because of weather conditions and peripheral vehicle flow. Furthermore, as the number of elderly drivers is expected to increase, it is also difficult to use them as subjects considering physical fitness and traffic safety. We are now constructing an indoors experimental system to overcome these problems.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance provided during the course of this study by Mr. Mii, Mr. Miki; students at Osaka University, Department of Civil Engineering.

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