SAFETY EVALUATIONS OF ROAD SPACE FROM THE PERSPECTIVE OF THREE-DIMENSIONAL ALIGNMENT AND LENGTH OF ROAD STRUCTURES

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ABSTRACT

Studies of the concentration of traffic accidents in Japan show that about half of all accidents causing casualties on arterial roads occur on about 6% of their total simple road sections and at about 4% of all intersections.
Although traffic accidents are caused by complex combinations of three factors, human beings, vehicles, and roads, human factors are the most common causes of accidents. However, the existence of hazardous spots shows that the contribution of road factors to accidents at these locations is greater than elsewhere.
Under the criteria for the geometrical design of roads, the minimum values for elements such as horizontal alignment, vertical alignment etc. are set according to the design speed, and although there are basic concepts concerning desirable combinations and undesirable combinations of the horizontal alignment and the vertical alignment, there are few detailed regulations such as the combination of numerical values. Roads have a three-dimensional alignment created by combining the horizontal alignment and the vertical alignment, and at the same time intersections are located at intervals along their length. Therefore, to accurately evaluate the safety of a road, it is necessary to treat it as a space that has a three-dimensional alignment and a certain length.
From this perspective, an accident data base was used to perform an analysis to clarify the conditions of road structures where traffic accidents occur easily. This report presents the results of such analysis of the safety of a road from the perspective of space with three-dimensional alignment and length, and it advocates the view that to truly improve road safety, it is important to not only provide design standards for individual structural elements, horizontal alignment, vertical alignment etc., but to also give full consideration to combining these elements.

KEY WORDS

accident analysis, road structure, road alignment, delineator

1. Introduction

Road traffic comprises 3 elements: humans (drivers), vehicles, and roads. Traffic accidents occur as a result of flaws in any one of the three elements or flaws caused by interaction between the three elements (Shinar 1978). Factors related to the human element are thought to be the most common cause of accidents, but there are hazardous spots in any country. In Japan, about half of all accidents involving casualties on simple road sections of arterial roads occur on about 6% of their total sections. The cause of such accidents is likely to be human error induced by the road and/or traffic environment. Generally, each country uses criteria for road design that defines specific values for each item of horizontal and vertical alignment according to the design speed (SETRA 1994, etc.), such as the Road Structure Ordinance (Japan Road Association 1983) in Japan. However, safety may be lowered by a combination of items. For example, a design deemed as being safe only from the viewpoint of radii of curves could be unsafe if it is in a section with vertical alignment. Also, safety could be reduced due to the combination of that section and the preceding sections, such as in a section with successive curves.

Therefore, in this study the relationship between accidents and the combination of horizontal curve and vertical grade or the combination of horizontal and vertical alignment in successive sections is analyzed. Furthermore, analysis is made on the relationship between accidents and the combination of horizontal alignment, and delineators which is believed to be effective in reducing accidents in curved sections.

2. Methods of analysis

2.1 Applied data

In this study, analysis is conducted using the Integrated Traffic Accident Database, which combines statistical traffic accident data on the occurrence of traffic accidents, and the Road Traffic Census data on road traffic environments. Furthermore, MICHI, the data base for road management, is combined with the Integrated Traffic Accident Database in this analysis to understand detailed road structures and affiliated facilities. The Road Control Database is only available for the National Roads (total length: 21,828 km as of FY 2001) under the direct administration of the Ministry of Land, Infrastructure and Transportation. Thus, the analysis covers sections of these roads.

2.2 Methods of analysis

In this study, accident ratio (accident/billion vehicle km) is used to indicate the occurrence of traffic accidents and is calculated for each road structure condition at the locations of traffic accidents. Quantitative data such as radius of curve and vertical alignment is divided into appropriate increments for calculation of the accident ratio.

3. Results

3.1 Relationship between accident ratio and combination of horizontal and vertical alignment

The relationship between the accident ratio and the radii of curves (Fig. 1) is analyzed. And the relationship between the accident ratio and vertical grade (Fig. 2) is analyzed. In the analysis of the radii of curves, only the data for level sections is used, and in that of the vertical grade only the data for straight sections is used. In addition, the relationship between the accident ratio and the combination of radius of curve and vertical grade (Fig. 3) is analyzed. Note that in the calculation, transition curve sections are included in the curved sections. Also, a section with a vertical grade of less than 1% is deemed to be a level section.

The results of the analysis show that for curve radii of fewer than 400 m, the smaller the radius, the higher the accident ratio. However, for curve radii of over 400 m, the accident ratio does not decrease, and tends to level off or increase only slightly. Among the combinations of curve radii and vertical grade, the accident ratio is found to be higher for a small curve radius combined with a small vertical grade, and for a large curve radius combined with a small vertical grade. The accident ratio is also found to be higher in straight sections and level sections. These results suggest that sections with small curve radii have higher accident ratios due to the difficulty of negotiating sharper curves. On the other hand, the reason for the rise in the accident ratio at easier curve or grade is assumed to be that an easier curve or grade makes the driver more relaxed, resulting in increased driving speed with lowered attention.

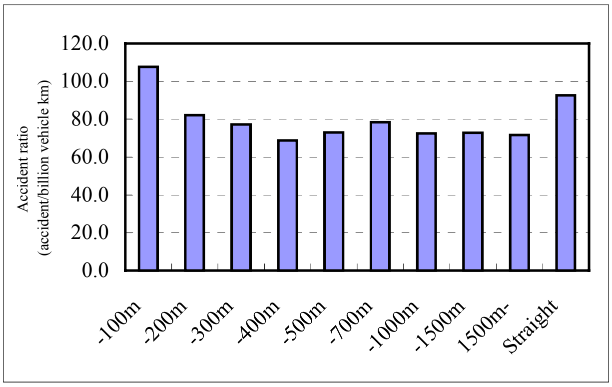

Fig. 1 Relationship between accident ratio and radius of curve

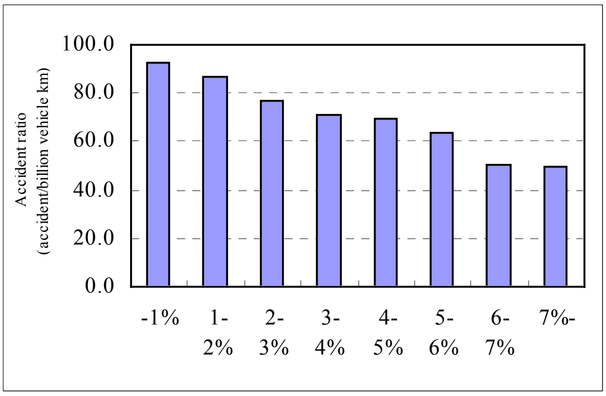

Fig. 2 Relationship between accident ratio and vertical grade

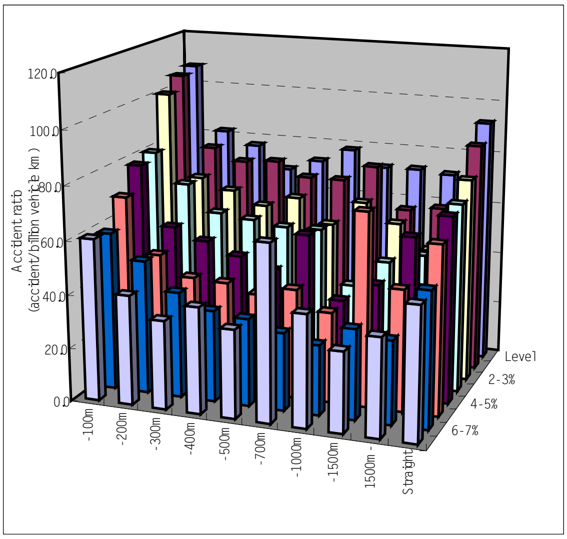

Fig. 3 Relationship between accident ratio and combination of radius of curve and vertical grade

For more detailed understanding, the effects of left- or right-hand curves and an upgrade or downgrade from the perspective of the primary party are analyzed (Fig. 4). Here, the traveling direction is decided by assuming that the primary party was driving in the lane where the accident occurred in the case of a rear-end collision, and driving in the lane opposite to the one where the accident occurred in the case of a head-on collision, using data on location of accidents at the time of the accident. Categories of accidents other than rear-end collisions and head-on collisions are not addressed in this study due to the difficulty of determining in what direction the primary party was driving.

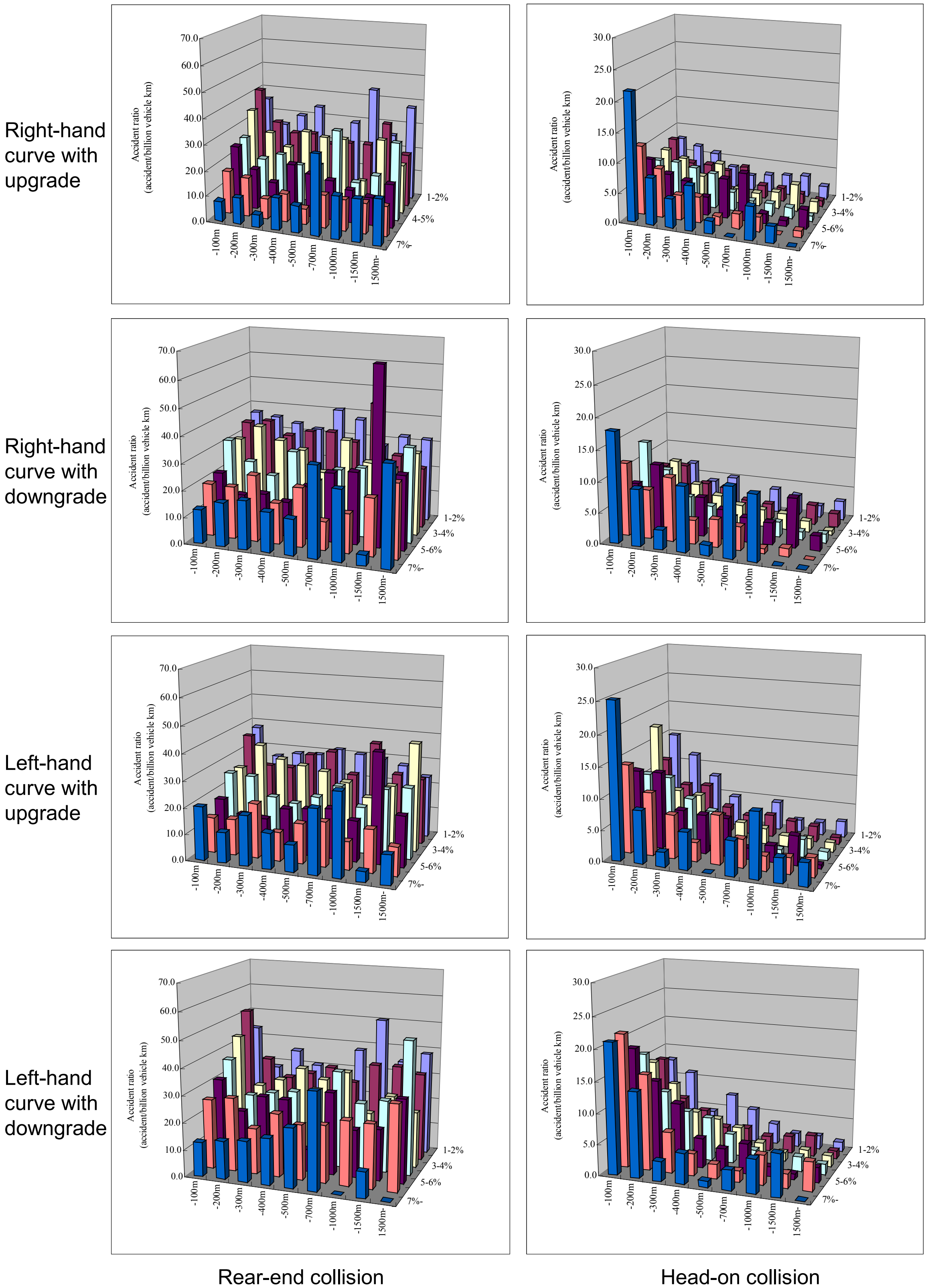

Fig. 4 Relationship between accident ratio and combination of radii of curves and vertical grades

The analysis results show that the accident ratio tends to be higher for downgrades than for upgrades. This is presumably caused by the tendency to exceed the speed limit on downgrades. As for head-on collisions, the accident ratio is higher for left-hand curves than for right-hand curves, probably due to the tendency to cross into the opposite lane on left-hand curves compared to right-hand curves due to the centrifugal force of driving on the left in Japan.

On the other hand, regarding the relationship between the accident ratio and combinations of curve radii and vertical grades, for head-on collisions, the smaller curve radius or the larger vertical grade, the higher the accident ratio, both for left- and right-hand curves. Furthermore, combinations of smaller curve radii and large vertical grades tend to increase the accident ratio. On the other hand, for rear-end collisions, the accident ratio is high even for large curve radii as well as small curve radii, and the smaller the vertical grade, the higher the accident ratio as is the case for all accidents. It is considered that a gentler alignment makes the driver more relaxed, inducing higher speed and lowered attention.

3.2 Relationship between accident ratio and combinations of alignments in successive sections

The relationship between the accident ratio and combinations of radii of curves in successive sections is analyzed (Fig. 5). Here, accident ratios are calculated for each increment of difference between the radii of two successive curves in an S-curve. Accident ratios are calculated for each increment for the smaller radius of the two curves. Note that accident ratios are calculated for accidents that occurred in either of the two curves in S-curves.

The results of analysis show that the accident ratio reaches an extremely high level if the differences between the first half and the second half of an S-curve become larger in the increment of less than 100 m for radii of curves. Regarding other curve radii, although not as conspicuous as curves of smaller than 100 m radius, the larger the difference in curve radii, the higher the accident ratio. This is presumably because drivers find it difficult to cope with a large change in the radii of S-curves.

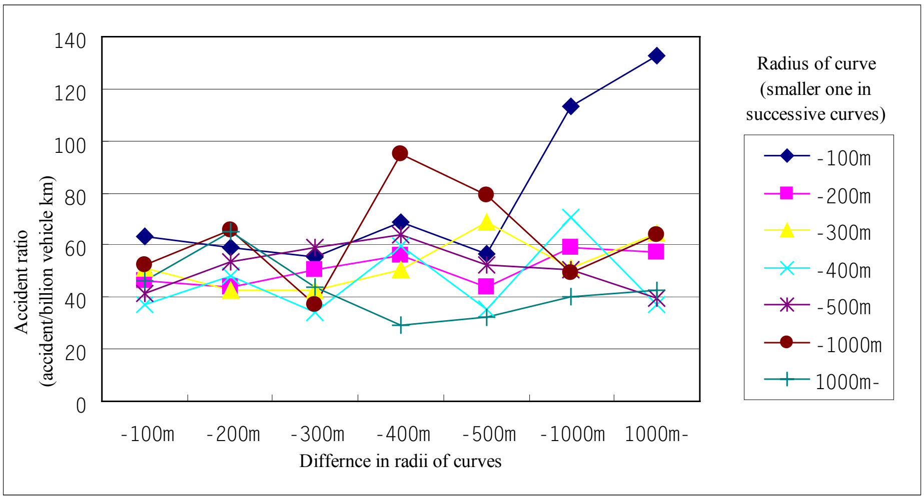

Fig. 5 Relationship between accident ratio and combinations of alignments in successive sections

Next, the relationship between the accident ratio and combinations of vertical grades in sags and crests (Fig. 6) is analyzed. Here, accident ratios are calculated for each increment of difference between two successive vertical grades. The ratio is also calculated for each increment of vertical grade for the smaller vertical grade of the two sections. A section with a vertical grade of less than 1% is deemed as being a level section, as is the case in 3.1 above.

The results show that the accident ratio tends to rise for a smaller difference between the vertical grades if the smaller one is within 1–2%. Here, if there is a small difference between successive vertical grades, the speed tends to change without the driver noticing due to the difficulty in grasping a change in vertical grade. The above facts suggest that a driver will fail to recognize the degree of vertical grades, leading to a higher accident ratio, if the difference is small between vertical grades of successive sections consisting of a sag or crest. Also, the smaller the difference between vertical grades, the smaller the value of the vertical grade itself. It is likely that the smaller the difference between vertical grades, the higher the accident ratio, as the accident ratio is higher for a smaller vertical grade, as stated in section 3.1.

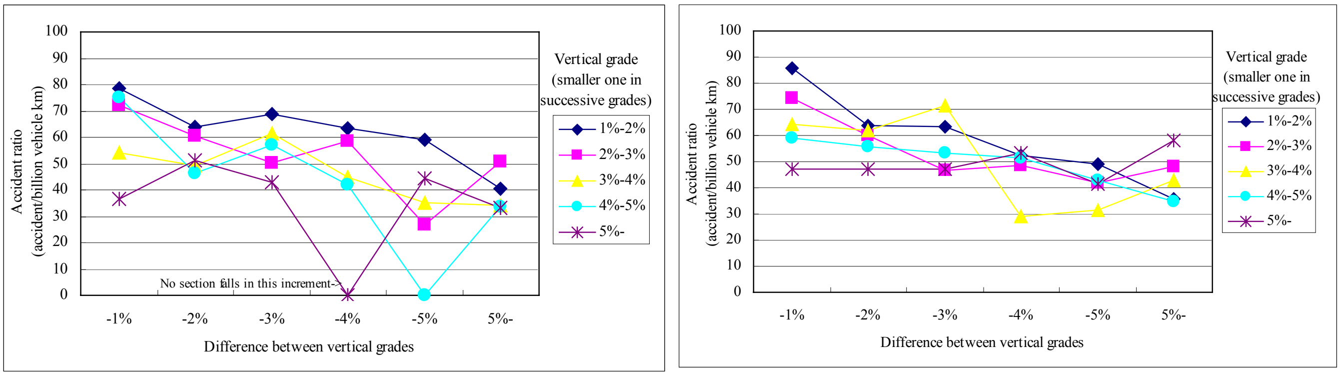

Fig. 6 Relationship between accident ratio and combinations of vertical grades in successive sections (left: sag, right: crest)

Here, both the horizontal curves and vertical grades are analyzed without distinguishing the traveling direction of the primary party. However, the accident ratio will likely rise when driving from a section with a gentle curve into a section with a sharp curve because of the larger speed change. In a future study we will investigate the differences between the direction of driving from a gentle curve into a sharp curve and the opposite direction and between driving from a small vertical grade into a larger vertical grade and the opposite direction. On the other hand, the risk of an accident may becomes higher in the case of approaching a curve after driving on a long straight section as a result of being more relaxed with lowered attention. The risk also increases if the radius of the curve or the vertical grade changes within a shorter section because the driver may find it difficult to respond to rapid changes. Accordingly, we will investigate the relationship between accident ratio and length of successive sections.

3.3 Various facilities and accidents

The accident ratio changes according to road alignment and various facilities. Here, the relationship between the presence of delineators and accident ratio (Fig. 7) is analyzed. As delineators are thought to be effective in reducing accidents in curved sections at night, the accident ratio for night-time accidents is calculated. The result shows a lower accident ratio in sections with delineators. From a safety viewpoint, it would be effective to provide supplementary facilities such as delineators for sections in which road alignment is difficult to modify due to geographical conditions, etc.

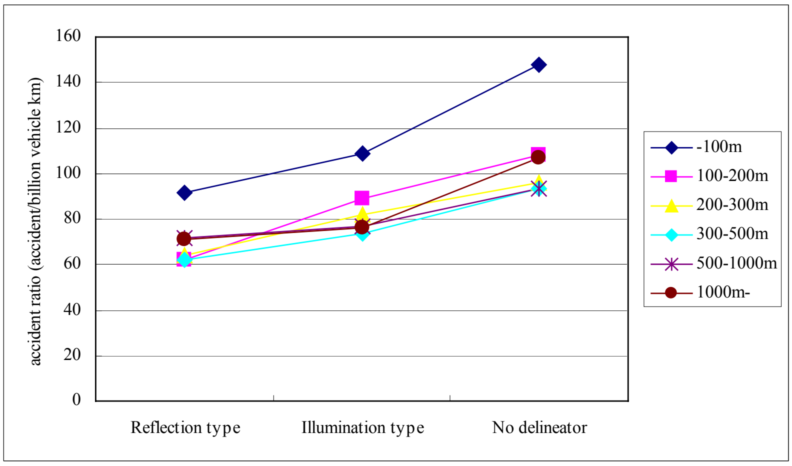

Fig. 7 Relationship between accident ratio and presence of delineator
(for each radius increment in night-time accidents)

4. Summary

In this study we investigated road safety by focusing on combinations of horizontal and vertical alignment or combinations in successive sections.
We first analyzed the relationship between the accident ratio and curve radii, and then the relationship between the accident ratio and vertical grade. The results show that the accident ratio increases with smaller curve radius, but the accident ratio is also high even for large curve radii. Furthermore, the accident ratio is higher for a smaller vertical grade, and increases in both cases of a small curve radius with a small vertical grade and a large curve radius with a small vertical grade. The reason why the accident ratio rises in spite of gentler alignments is thought to be due to the driver relaxing, and therefore driving faster with less awareness. The driver's attention should therefore be alerted by road markers even for sections with gentler alignments, as well as for those with sharper alignments.

We also analyzed the relationship between the accident ratio and left- or right-hand curves, as well as the relationship between the accident ratio and up- or down-grades, from the perspective of the primary party. The results show that the accident ratio tends to be higher for a downgrade than for an upgrade, probably due to the driver exceeding the speed limit on a downgrade. Road markers should therefore be used to slow down drivers on downgrade sections. Regarding head-on collisions, the accident ratio is higher for left-hand curves than for right-hand curves, probably due to the higher tendency to cross into the opposite lane on left-hand curves than on right-hand curves due to the centrifugal force. Accordingly, it is important to urge drivers to slow down or make them more alert before entering a left-hand curve.

Next, we analyzed the relationship between the accident ratio and combinations of successive sections. First, we analyzed the relationship between the accident ratio and difference in radii of two successive curves comprising an S-curve. The results show that the larger the difference in the radii of the two curves, the higher the accident ratio. This is presumably due to the driver's difficulty in negotiating the difference in radii. For safety, it is therefore desirable to reduce the difference in the radii of the two curves when designing a curved section.

We also analyzed the relationship between the accident ratio and difference in vertical grades of two vertically graded sections comprising sags or crests. The results show that the accident ratio tends to rise in case of a change from a gentle grade to another gentle grade in both sags and crests. This may be caused both by the increase in accident ratio due to small vertical grade as stated above, as well as the difficulty of recognizing a change in vertical grades. Therefore, the difference in vertical grade of sections with dips or crests should not be made too small, or measures should be taken to make drivers recognize a change in vertical grade.

We also found that the nighttime accident ratio is lower in curves with delineators compared with those without them. Nighttime driving could therefore be made safer by installing delineators, for example, or informing drivers of the radius or direction of a curve in locations where it is difficult to modify the radius due to topographical conditions or facilities along the road.

In a future study we will investigate the relationship between the accident ratio and driving speed or traffic violations at the time of accidents by considering the behavior of vehicles or actions of drivers, in addition to combinations of horizontal and vertical grades and combinations of alignments of successive sections. Regarding combinations of successive sections, we will investigate cases of driving from a gentle curve into a sharp curve and vice versa, and driving from a small vertical grade into a larger vertical grade and vice versa, and will examine the relationship between the accident ratio and lengths of successive sections.

REFERENCES

Shinar, D. (1978) Psychology on the Road - The Human Factor in Traffic Safety.
SETRA (1994) AMÉNAGEMENT DES ROUTES PRINCIPALES.
Japan Road Association (1983) Description and Application for Road Structure Ordinance.