Analysis on Causes of Four-Wheeled Vehicle Accidents in Hilly and Mountainous Area

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Received on March 20, 2019

ABSTRACT: In previous report, four-wheeled vehicle accidents in hilly and mountainous area are paid attention to Nagano Prefecture. These accidents are vehicle alone or head-on collision accidents caused by lane departure on the road with up and down slope and curve. This paper researched the risk of accidents using statistical data analysis related to road alignment. Furthermore, the authors investigated additional accident cases in hilly and mountainous area occurred in 2016, and reconstructed the accident using accident simulation to find out the influence of road alignment. In results, the risks of accidents, which are calculated the number of fatal accidents divided by the number of all accidents, at downhill with right curve and uphill with left curve in Nagano are higher than those in the whole of Japan. These accidents were caused by lane departure, and the vehicles fell to the outside road. The occupants died with multi-injured body parts by these accidents. The accident reconstruction simulation indicates the road slope affects the curve recognition time. Therefore, the road alignment becomes accident hazard factor, and is sure to indicate accident hazard map to prevent accidents in hilly and mountainous areas.

KEY WORDS: safety, statistical accident analysis, accident investigation and analysis, Hilly and mountainous area (C1)

1. Introduction

In order to achieve the world’s safest road traffic, which is the goal of the 10th Traffic Safety Basic Plan 1) established by the Cabinet Office, it is required that effective measures by grasping the traffic accident situation appropriately including the local areas. For example, Nagano Prefecture is the region with the highest altitude of residence area in the whole of Japan 2), and it is considered that the traffic situation is peculiar to the area which is different from the metropolitan area, such as pass road, snowed or freeze road in winter etc. In addition, the number of fatalities in Nagano Prefecture in 2017 is 79, which is not so many but has been almost constant since 2012 3). The number of fatalities in Nagano Prefecture has a weak tendency to decrease compared with the whole of Japan 3).

In previous reports 4) 5), the authors conducted statistical analysis and cluster analysis using traffic accident statistical data, and tried to extract remarkable characteristics of traffic accidents occurred in Nagano Prefecture. As a result, the fatal accidents in Nagano were a lot of vehicle to vehicle or vehicle alone accidents by four-wheeled vehicles, especially accidents in hilly and mountainous areas with up or down slope with left or right curves were indicated as remarkable accidents (Figure 1). Furthermore, the authors investigated four locations of fatal accidents where four-wheeled vehicle accidents occurred in hilly and mountainous area out of 103 fatal accidents (excluding train accidents) in Nagano Prefecture in 2016 6). As a result, common factors analyzed are, (1) accidents due to lane departure, (2) difficulty to recognize curves on roads with longitudinal slope and left or right curve, (3) existence of straight section where speed tends to come out before accident point. Therefore, in this study, the authors analyzed the traffic accident risk due to the road alignment from the analysis using traffic accident statistical data and accident reconstruction simulation based on the additional accident investigation. The purpose of this study is to clarify the causes of accidents occurred in hilly and mountainous areas due to the road alignment.
2. Analysis method

2.1. Flow of this study

The flow of this study is shown in Figure 2. The first step is to conduct nationwide comparative analysis using traffic accident statistical data as macro statistical analysis and to extract features of traffic accidents peculiar to the area from the difference (4). Furthermore, similar areas are identified using cluster analysis and principal component analysis, and the characteristics of the area are deepened from the comparison (5). The second step is to clarify the true cause of accidents from the accident investigation of each case on the characteristics of the accident in the area obtained from macro statistical analysis (hereinafter referred to as micro accident analysis) (6). And as the last step, the authors will devise measures to prevent accidents from the viewpoint of human, roads, and vehicles based on true accident causes. Furthermore, hazard factors are specified for preventing accidents.

In this report, the authors analyzed the causes and accident risk due to road alignment in hilly and mountainous areas identified in the previous report (6) from the investigation of accident locations where actually fatal accidents occurred in Nagano Prefecture as the micro accident analysis of the second step. The points of view are statistical accident data to evaluate accident risk level, characteristics of occupant injury due to these accidents and the cause of accidents by road alignment using accident reconstruction simulation. From these results, the authors attempted to clarify the real causes of these accidents in hilly and mountainous areas.

2.2. Statistical accident analysis method for accident risk and occupant injury

In order to evaluate the degree of accident risk due to the road alignment, the statistical analysis was conducted using traffic accident data from the following literatures on traffic accident statistical data for the whole of Japan and Nagano Prefecture (hereinafter referred to as macro analysis). The authors counted the total accidents within three years to mitigate the effect of deviation due to a single year.

Using these data, the authors compared the numbers of fatal accidents and all traffic accidents that occurred in the whole of Japan or Nagano Prefecture. Since fatal accidents in Nagano Prefecture are considered to be affected by road alignment, the analysis focused on the items related to roads shown in Table 1. In addition, the authors evaluated the ratio of the fatal accidents to all traffic accidents as the accident risk level. Moreover, the items of personal injuries related to the four-wheeled vehicle occupants were also analyzed to clarify the characteristics of the accident in hilly and mountainous areas.

2.3. Accident location investigation

In the previous report (6), four-wheel vehicle fatal accidents in hilly and mountainous areas were classified by road alignment, and the accident modes on the curved road were considered as shown in Figure 3. There are four modes consisting of combinations of longitudinal slope with left or right curves, and four modes consisting of combinations of pass or sag road with left or right curves. In this report, the authors selected and investigated a traffic accident location on the pass road with a curve whose accident mode was not investigated in previous report (6).
2.4. Investigation on visibility of curve using accident reconstruction simulation

The visibility of the curve was examined using the accident reconstruction simulation based on the micro analysis on the pass road. PC-CRASH ver11.1 (DSD) was used for accident reconstruction simulation. The road shape and the surrounding environment were reproduced based on the investigation information of the accident location, and the visibility of the curve from the vehicle due to the road alignment was analyzed. In the investigation, the authors defined the time from the time when it can be recognized that the own lane is curving to time at the collision point as the curve recognition time (Tc). The recognition of the curve was judged by the point when curved road appeared outside the range where driving lane was linearly extended using the reconstruction image from the driver’s viewpoint in the simulation. That is the margin travel time between the point where driver can recognize the curved road ahead and the collision point. The Tc is calculated and compared for the curved road of accident location.

3. Result of accident statistical analysis for accident risk

3.1. Rate of fatal accidents for type of road alignment

Based on the analysis contents of the previous chapter, the authors analyzed the accident risk level that the road alignment exerts using accident statistical data.

Figure 4 shows the comparison of rate of fatal accidents by road alignment. Looking at the data from the whole of Japan, the accident risk level on downhills roads with curve is approximately 3 to 4% and tends to be high. The accident risk level on downhill roads with left curve is higher than that of the downhill roads with right curve. On the other hand, focusing on Nagano Prefecture, the risk of accidents on downhill roads with curve is similarly high, but the accident risk level on downhill road with right curve is significantly higher than that of the whole of Japan (approximately 6.2%). In addition, the accident risk level on uphill with left curve is the highest (approximately 7.4%). From these results, it shows that the accident risk level on downhill roads where the vehicle’s speed tends to be high, and the accident risk level on downhill road with curve is about 2 to 3 times higher than that of flat road. Furthermore, in Nagano Prefecture, the accident risk level on downhill roads with right curve where vehicle alone accidents caused by road departure occur (Case A) and on uphill roads with left curve where head-on or vehicle alone accidents caused by lane departure (Case B), are about twice as high as that of the whole of Japan. These results support the case of the fatal accident that occurred in 2016 investigated in the previous report (6).

3.2. Rate of fatal accidents for type of road shape

Figure 5 shows the comparison of rate of fatal accidents by road shape. The accident risk level on non-intersection roads with curve is approximately 4%, which is about 4 times higher than that of the intersections. Furthermore, it shows that the accident risk level on non-intersection roads with curve in Nagano Prefecture is somewhat higher than in the whole of Japan. This also confirms that the accidents on curved road have high accident risk level.

3.3. Rate of fatal accidents for type of accidents

Figure 6 shows the comparison of rate of accidents by type of accidents for vehicle to vehicle accidents and vehicle alone accidents. Both in the whole of Japan and in Nagano Prefecture, the risk of vehicle alone accident is high, and it is about 3 to 7 times higher than head-on collision. In particular, fall down accidents due to road departure have high risk of accidents. The risk of accident for vehicle alone accident in Nagano Prefecture is about twice as high as that of the whole of Japan, and the risk of fall down accidents due to road departure is approximately 48.8%.
When considered together with the results of road alignments, it is presumed that the risk of vehicle alone fall down accidents due to road departure, which occur by turning at curve inappropriately, is extremely high.

4. Result of occupant injury

4.1. Situation of injuries for four-wheeled vehicle occupants

To clarify the risk of four-wheeled vehicle accidents in hilly and mountainous areas, the situation of injuries for four-wheeled vehicle occupants was analyzed using statistical accident data. Figure 7 shows the main body part of injuries for fatalities in four-wheeled vehicle accidents. The figures in parentheses show the total number of fatalities from 2014 to 2016. In Nagano Prefecture, the percentage of multi-injured, which has multiple fatal injuries, is about twice as high as that in the whole of Japan. Moreover, Figure 8 shows the situation of the parts of contact for fatalities. The percentage of ejection or contact to steering wheel are many in Nagano Prefecture compared to the whole of Japan. From these results, it is presumed that the four-wheeled vehicle fatal accidents in Nagano Prefecture are vehicle alone fall down accidents with multi-injured and ejection and have high risk accidents.

Then, in order to confirm the injury situation in more detail, the injury situation was analyzed using the data of fatal traffic accidents occurred in Nagano Prefecture in 2016. Figure 9 shows the proportions of the main body part of injuries for the type of accidents and hilly and mountainous areas or not. Here, the hilly and mountainous area was classified as an area with ±3% or more of the road slope before or after the accident point using the Geospatial Information Authority of Japan Map\(^{(13)}\). It shows that the percentage of multi-injuries for vehicle alone accidents in hilly and mountainous areas is high (approximately 30%) compared to vehicle to vehicle accidents or out of hilly and mountainous areas. However, because the number of investigated accidents is limited, further investigations are necessary in the future.

Furthermore, Figure 10 shows the percentage of body part of injuries in case of fall down accidents or not for vehicle alone accidents. Although the number of surveyed accidents is small, there is room for consideration, but it can be said that, occupants tend to be multi-injured in the case of fall down or rollover accidents.

4.2. Summary of accident analysis in hilly and mountainous areas

According to the results of macro analysis above, in many four-wheeled vehicle alone fatal accidents in hilly and mountainous areas, a vehicle leads from lane departure to road departure caused by some reasons, and falls outside the road, resulting in fatal multi-injured. This type of accident is a high accident risk level, that is, high rate of fatal accidents. In particular, it is considered that downhill road with right curve is a point where fatal accident is likely to occur because of speeding. These results support the causes which were investigated and analyzed in the previous report\(^{(6)}\). Therefore, it is considered that the type of accident on downhill road with right curve is a remarkable and a high accident risk level in hilly and mountainous areas for four-wheeled vehicle accidents. On the other hand, there are still many unknown causes about the accidents on uphill roads with left curve, and it is necessary to investigate human factors and vehicle characteristics continuously.
Table 2  Contents in Case G-1

| Items                        | Contents                                      |
|------------------------------|-----------------------------------------------|
| Day and night, weather       | Day, clear                                    |
| 1st party                    | K-commercial car, Male of 74 years old        |
| 2nd party                    | Large truck, Male of 56 years old             |
| Road type                    | National highway                              |
| Road width                   | Single lane on each side, 8.8m                |
| Road slope before AP/after AP| 5.0% / -8.7%                                  |
| Road radius of curvature     | R=370m                                        |
| Length of straight lane before AP | 600m                                        |

5. Result of accident investigation and accident reconstruction

5.1. Accident investigation: Pass road with left curve accident Case G-1

The authors investigated the accident location on pass road with left curve (Case G), which was lacking in the micro accident analysis in the previous report (6).

This accident occurred on national road in Shiojiri-city, Nagano Prefecture. The first party’s vehicle was a K-commercial car (small mini truck), the second party’s vehicle was a large truck. The first party’s K-commercial car, traveling through left curve and departing from own lane to oncoming lane, and head on the second party’s large truck. An outline of the accident is shown in Table 2. In addition, Figure 11 shows photographs at the point of 100 m and 30m before the Accident Point (AP) and the AP. A straight section (approximately 600 m) of a long uphill slope (approximately 5.0%) continues before the AP, and the road condition which is easy to get speed is inquired. The AP is the pass where the uphill road ends and the downhill road with gentle left curve starts. This left curve is difficult to recognize before the AP if they are driving carelessly. Under these circumstances, it is estimated that this accident happened due to deviating from the lane without steering along the left curve because the recognition of the left curve was delayed, and colliding against the large truck in opposite lane.
5.2. Study on visibility of curve using accident reconstruction simulation

Based on Case G-1, an accident case on pass road, the visibility of the curve affected by the road slope was examined using accident reconstruction simulation.

The simulation model around the accident point is shown in Figure 12. The longitudinal slope of the pass and forest condition on the left and right of the road are modeled. From the accident situation, the simulation model reconstructed the scene in which the first party’s K-commercial car departed from own lane to oncoming lane along the trace line of extension of the straight section, and head on the second party’s large truck. Figure 13 shows the road conditions seen from the first party’s line of sight of at the point where the curve recognition time (Tc) defined in Chapter 2 and before Tc. The Tc was 2.5 seconds at a vehicle speed of 50 km/h. The appearance of the driving destination in front of this curve recognition point seems to be a straight line surrounded by forests on both sides. Since these results were almost same as the evaluation results of actual driving at the location, it is considered that this model can reasonably evaluate the driving situation. Therefore, the influence of the curve recognition time by the road slope was investigated using this simulation.

The average road slope on the near side of the current condition was 1.27%, and the road slopes of flat (0%) and double (2.54%) were also simulated to compare the visibility of curve. In order to evaluate the steepness of pass, the average road slopes on far side of pass were also set to 0 and 2 times. The results are shown in Figure 14. From these results, it can be confirmed that the curve recognition time of the traveling destination becomes short when the road slope becomes large, and the steering operation for the curve tends to delay. The curve recognition time at approximately 1% road slope is twice as long as that at flat. Regarding the influence of misidentification accidents due to road alignment, the analysis by Institute for Traffic Accident Research and Data Analysis suggests the influence as well. Assuming that free running time before braking is 0.75 sec and the deceleration is 7.85 m/s², the time until stopping at 50 km/h is approximately 2.5 sec. It shows that there is no margin even with the current road slope. In the case of steeper slope or vehicle speeding, severer situation can be confirmed. From the mention above, it was found that the recognition of the curve is delayed on a road with a slope where the curve ahead cannot be seen, such as near pass, and it causes an accident by lane departure and road departure due to an operation error. The authors think that the same tendency can be said to the point of a curve where one side is a mountain and the visibility is bad.

6. Discussion

6.1. Accident hazard factors related to road alignment

Based on the analysis results above, accident hazard factors in hilly and mountainous areas are considered. The typical four-wheeled vehicle accident in hilly and mountainous areas was an accident involving lane departure or road departure. As shown in Figure 15, the causes of lane departure are considered to be overspeed, misrecognition of the lane, operation error, or careless driving. Overspeed is related to sideslip limit (15) obtained from vehicle velocity, curvature of road, and cross-fall of road. The misrecognition of the lane is considered to be affected by curvature of road and road alignment of longitudinal slope as confirmed in the accident reconstruction simulation. Furthermore, as a factor of speeding, it is considered to be influenced by the length of straight section before the curve and the road alignment of longitudinal slope based on the legal speed. In other words, it is considered that the longer straight section ahead is, the easier it is to increase the vehicle velocity, and the downhill road is a factor that tends to increase the vehicle velocity.

Therefore, it is considered that hazard factors that cause an accident in the hilly and mountain area are curvature of road, road alignment of longitudinal slope, cross-fall of road, and length of straight section ahead. It is inferred that the accident risk level is determined from the relation between the vehicle velocity, the sideslip limit, and the visibility of the curve. In the future, it will be possible to create an accident hazard map that leads to prevention if the accident risk from these relations can be evaluated. However, there are other factors, such as human error, for example operation error and careless driving, and vehicle characteristic. It is also necessary to take into account these factors as hazard factors.

6.2. Preventing lane departures and road departures

In order to prevent a four-wheeled vehicle accident in hilly and mountainous areas, it is extremely important to prevent lane departure and road departure. For that purpose, as mentioned in the previous report (6), appropriate communication between the road and the driver in real time is required. It is important to advance the driving support technology and to improve the appropriate guidance technology on the road side. These technologies should be preferentially developed in the future. In particular, it is required to consider these factors due to road alignment in hilly and mountainous areas where visual recognition tends to be delayed.

7. Conclusion

In this study, the authors focused on four-wheeled vehicle accidents in hilly and mountainous areas as fatal accidents occurring frequently in Nagano Prefecture, and conducted macro accident analysis, micro accident analysis, and accident reconstruction analysis to analyze causes due to road alignment. The conclusions obtained are as follows.
From the results of accident statistical analysis for accident risk level, which is defined as the ratio of the number of fatal accidents to that of all traffic accidents, the risk level in Nagano Prefecture for the accidents on downhill road with right curve and uphill road with left curve are approximately twice as high as that of the whole of Japan.

The accident risk level for four-wheeled vehicle alone accidents is high, especially for fall down accidents due to road departure. This accident risk level is approximately 48.8%.

The lots of occupants in this type of accident have multi-injured fatal damage. The occupants were higher injured in the fall down and rollover accidents in Nagano than those in the whole of Japan.

From the results of accident investigation and accident reconstruction simulation for the accident near the pass with curve, the curve recognition time for 1% slope pass road is delayed by approximately 2 times compared to the flat road. It turned out that the road slope causes the delays of curve recognition ahead.

It is considered that the hazard factors of road alignment for accidents in hilly and mountainous areas are curvature of road, longitudinal slope of road, cross-fall of road, and length of straight section ahead. The authors think that these relations can create accident hazard maps to prevent accidents.

This paper is written based on a proceeding presented at JSAE 2019 Annual Congress (Spring).

Acknowledgement

The authors would like to thank Nagano Prefectural Police Agency for providing Nagano accident data, and Professor Hermann Steffan of Graz University of Technology for supporting accident reconstruction simulation.

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