Research on Traffic Safety of Freeway Upgrade Section

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Abstract

In this paper, upgrade section was classified based on linear combination form and whether or not constructing the climbing lane. Traffic accident characteristics on the upgrade section were analyzed from the viewpoint of vehicle type, accident type and time distribution. For in-depth study of accident causes, the paper analyzed traffic flow operation characteristics and discussed main influencing factors of traffic flow situation. In addition, the influence zone of upgrade section was put forward and defined. This laid good foundation for follow-up study on influence mechanism between microscopic traffic flow operation characteristics and traffic safety. Finally, the corresponding safety improvement measures were proposed.

Keywords: freeway; upgrade section; accident analysis; traffic flow characteristic; the influence zone; safety

1. Introduction

As the main artery of the highway transportation, freeway plays an increasingly important role in the development of the national economy. According to the statistics from the Ministry of Transportation of the People's Republic of China, by the end of 2011, the national freeway mileage has amounted to 84,900 kilometers and lane mileage to 375,900 kilometers. However, freeway traffic accident is increasing day by day and it has gradually become a prominent social problem, causing huge economic losses to the country. Statistical data shows, foreign freeway accident rate is about 30% ~ 51% of general highway, the mortality rate is about 43-76%. In contrast, both freeway accident and mortality rate in our country are far higher than the general road, respectively about 4 times and 8 times of general highway and serious traffic accident that produce many casualties is often seen (Junhua Wang, Shouen Fang, & Yuren Chen, 2011). One of the important reasons is that the initial freeway planning and design theory was not perfect in China, resulting in some imperfect roads in the existing highway network, especially in western mountainous region, such as poor road alignment, improper safety facilities, imperfect traffic management measures etc. One prominent expression of poor road alignment is

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that limited natural environment results in many long and steep roads, which are often freeway traffic accident black-spots. The existing researches mostly focus on the downgrade facilities reconstruction, while the study about traffic safety improvement of the upgrade section is relatively weak.

Actually, when trucks volumes account for a larger proportion of freeway traffic flow, it should not be neglected that freeway upgrade section has significant effect on traffic safety, especially on particular longitudinal slopes, it become traffic bottleneck for trucks decelerating impeded the whole traffic flow on the upgrade section, which greatly affect road capacity and level of service. Previous researches on upgrade mainly focused on the determination of the gradient and gradient length (Ronggui ZHOU, Jiafeng SUN, & Wanyang WU, 2003), while the study on the factors of traffic flow characteristics and safety performance is less. On the other hand, some researches established related macroscopic traffic flow model to analyze the traffic stream on climbing lane. For instance, Werner Briton and Andrea Bressler (2004) studied traffic flow characteristics on upgrade of Germany freeway by continuous traffic monitoring and simulation software. In order to improve traffic safety situation on upgrade, the paper analyzed traffic flow operation characteristics of upgrade section, aiming at finding out potential security risks, proposing some countermeasures to minimize freeway traffic accident. It not only has important operation significance on preventing and dealing with traffic accident at complex traffic environment, but also play an important part in establishing modem freeway management mechanism and advancing the level of management.

2. The type of upgrade section

Traffic safety situation on freeway upgrade section is related to road geometric characteristics, linear combination form as well as traffic conditions and other factors. When driving on the freeway with design defects, high-speed vehicles would be in an unstable state and drivers would easily generate visual error (Gang Zhou, 2007). Yasser Hasasn and Sadi Easa studied the effects of highway horizontal and vertical linear combination on the driver’s vision. They found that when horizontal curve combined with convex vertical curve, the driver would misjudge that horizontal curve radius is less than the actual value; conversely, when horizontal curve combined with concave vertical curve, driver would consider the radius is larger than the actual value. In addition, freeway, with too long liner or excessively large slope, may greatly cause traffic accident. Since traffic states are significant differences among the different types of upgrade road, it is necessary to classify them.

According to China Design Specification for Highway Alignment (1994), the maximum degree of gradient on freeway should be between 3% and 6%. In this paper, the upgrade section was defined as the grade greater than 3% and the length greater than 500m.

Through collecting road design materials and observing traffic flow parameters, the upgrade sections were classified according to the linear combination form and whether constructing climbing lane. The first situation can also be divided into four types, including continuous upgrade section, upgrade-downgrade section, upgrade-liner section and upgrade-horizontal curve combination section. The study suggested that freeway generally meet the design specifications in terms of the selection of a single linear design, while it would be uncertain whether many liner combination forms meet safety requirements. The analysis of continuous upgrade section and upgrade-horizontal curve combination section may be relatively complicated than others.

Continuous 3km longitudinal slope with average grade greater than 3.5% commonly exist in Chinese mountainous freeway (Qing Xian Kuang, 2010). In order to overcome altitude difference and to meet the truck in a certain speed on uphill road, it is bound to form “step” continuous upgrade with the alternating combination long steep slope and short gentle slope for the limitation of mountainous terrain, in which truck would accelerate
or decelerate depending on the degree of gradient. Upgrade-horizontal curve combination section is always seen on mountainous area in China. Bluzz studied traffic accident on Germany freeway and found that the larger the radius of the curve is, the smaller traffic accident rate is, in addition, with the same curve radius, the smaller longitudinal grade is, the smaller the accident rate is. Actually, it is inevitable for combined sharp horizontal and vital curves with a smaller radius because of limited environment and construction funds. Many studies showed that the variation pattern of operating speed on the curved section is a more complex situation. It is similar to the situation on horizontal curve or a slope alone, while they also differ from each other.

3. Accident analysis and determination of factors of traffic flow characteristics on freeway upgrade section

3.1. Accident analysis

Compared with foreign developed countries, traffic composition in China is more complicated, mainly by mixed traffic with different performance and speed.

On upgrade, heavy-duty trucks decelerated caused by inferior operating capability, yet passenger cars’ speed was less affected by slope, which resulted in more significant speed differential between them, more passing demands and frequent changes in driving behavior so that traffic flow on grade road section disordered. Moreover, more trucks in traffic flow would reduce degree of freedom of cars, leading to significant decreases of road capacity and level of service on upgrade. In this case, traffic conflict may easily produce, including lane change conflict, rear-end conflict, merging and diving conflict causing by vehicle entering and leaving climbing lane. These are possible accident as follow: (1) rear-end between car and truck; (2) sideswipe between cars or between car and truck on adjacent lane; (3) hitting guardrail or fixtures etc.

Based on historical accident statistics during January 2006 to July 2010 of East Lushan segment of Nanjing-Hangzhou Freeway, the paper analyzed traffic accident characteristics on upgrade sections.

The length of upgrade section is 1.8km in the direction of Nanjing to Hangzhou, reversely 2.0km, accounting for 42.9%, 47.6% of the total length of East Lushan segment respectively. In the statistical period, the accidents of both directions were 26, separately accounting for 78.8% of 33 accidents, 70.3% of 37 accidents. Additionally, it occurred 8 (a total of 9), 3 major traffic accidents (a total of 3) in the respective direction. The analysis showed that the total number of accidents of upgrade accounted for 74.3% of 70 accidents of East Lushan segment, far greater than the number of downgrade; Major traffic accidents accounted for 21.2% of accidents on upgrade. The upgrade sections were more prone to traffic accidents than the downgrade and the other sections. Accident always occurred in the middle and rear part of straight slope section and vertical curve segment (Sitao Hu, Qiaojun Xiang, & Yanyu Zhu, 2013). Obviously, these sections should be regarded as the focus of traffic management and control.

Heavy-duty trucks and passenger cars are main vehicle types of upgrades on East Lushan. Fig. 1 is a scale map of vehicle type of traffic accidents on upgrades.
The main accident types of upgrade sections on East Lushan included rear-end, hitting guardrail or fixtures, respectively accounting for 55.7%, 19.2% and 13.5% of the total number of accidents. The reasons of rear-end were mainly due to speed differential between passenger cars and heavy-duty trucks, the insufficient safety distance and driver's improper operation. Hitting objects were mostly caused by driver's carelessness, fatigue driving, bad sight distance and illegal lane change etc. Fig. 2 showed the distribution map of traffic accident types on East Lushan section. It can be seen that rear-end is the most major and serious traffic accident form.

Fig. 3 is a time distribution map of traffic accident on upgrades of East Lushan section. During 18:00 to 6:00, the accident rate of the night is 76.9% in Nanjing to Hangzhou direction, reversely, 61.5% in the other direction, which are larger than those of the day.
Fig. 3. Time distribution map of traffic accident on upgrades of East Lushan section

Fig. 4 is a time distribution map of major traffic accident on upgrades. It showed that the severity of accidents of the night is far greater than that of the day. It is prone to have accident especially early in the morning from 2:00 to 6:00.

From the analysis of traffic accident characteristics of view, it is mainly due to the speed differences among different types of vehicles. The accident rate always increases with increasing average speed difference. In addition, traffic accident is also related to road geometry, traffic volume, the percentage of the trucks, climbing performance, load levels and driving behavior (such as speeding, fatigue driving) etc. Analysis found that the more complex the traffic composition is, the more confusion traffic movement is and they interfere with each other, which lead to traffic accidents more easily.
3.2. Main influencing factors of traffic flow

Studying accident mechanism on upgrade section ultimately comes down to analysis of traffic flow operation characteristics. However, there are many factors influencing traffic flow, for instance, road condition, traffic condition, traffic management and climate etc. Venkatachalam amizh Arasan and Shrinivas Shrikant Arkatkar (2010) discovered that the slope and slope length had significant effect on traffic flow characteristics, especially in mixed traffic, which have differences in vehicles’ physical dimensions, weight, engine horsepower, and acceleration rate. He also established a traffic flow model to study traffic flow characteristics and performance of different types of vehicles on the upgrade sections with different slopes. In this paper, based on a large number of measured data, traffic flow situation on upgrade under different road and traffic condition were researched by using simulation.

Many previous researches suggested that 3% of the slope is a division point of truck speed variation on upgrade (Ronggui ZHOU, Lishen JIANG, & Jiafeng SUN, 2004). Less than or equal to 3% of the slope has little effect on truck’s running speed, on the contrary, truck’s speed declines significantly, particularly the initial stage on upgrade, then speed decreasing gently until a stable and constant situation (Lu Tian, 2009).

Through the measured speed data, it was concluded that truck got through a series of process, accelerating, decelerating until close to constant state when it entered into upgrade from the straight sections. Truck’s running speed ranged from 30km/h to 70km/h. When the slope length was constant, speed reduction was largest at 5% grade, indicating that truck climbing performance had been significantly affected. In addition, with the same slope length, the steeper the slope is, the greater speed reduces; with the same grade, the longer the slope is, the greater speed reduces. The conclusion arrived an agreement with the highway and urban road geometric design issued by AASHTO (2004). Xiaoming Zhong, Xiaoming Liu and Jian Rong (2005) studied trucks operating speed on combined sharp horizontal and vital curves and found that running speed variation on combined sharp horizontal and vital curves is a more complex phenomenon, which is similar with effects that horizontal curves and longitudinal slope separately produce, while also has differences. Vehicle speed reduction is related to curve radius and the gradient.

In this study, Vissim was used to analyze the influences of setting climbing lane on traffic flow. Without climbing lane, since car was in a passive car-following state, average speed decreased dramatically and delay rate kept increasing. Inversely, when truck was separated into climbing lane, delay rate and speed discreteness in the whole traffic stream would be reduced. With the increment of traffic on upgrade, the improvement effectiveness was more apparent. Nevertheless, it did little work when traffic approached to the saturation, the capacity of climbing lane declined greatly. In terms of mix rate of truck, the study discussed upgrades without climbing lane. As the mix rate of truck increased, average speed decreased, while speed discreteness and overtaking rate first increased, then decreased. When the mix rate was 0.3, the level of traffic safety reduced to a minimum, having the greatest effect on speed and lane changing, and the minimum degree of freedom of traffic flow. Furthermore, the greater the difference between individual on traffic flow was, the more significant effect and it would easily generate traffic hazards.

In summary, main factors of influencing traffic flow include grade, length of slope, linear combination form and truck’s mix rate etc. Clearing this problem not only lays the foundation for follow-up study of the relationship between traffic flow characteristics and traffic safety, but also provides theoretical basis for optimization design and traffic management of the upgrade sections.

4. The concept of the influence zone of upgrade section
So far, most of the research in this area was conducted about the relationship between grade, slope length and vehicle speed, not indicating the specific influence scope of upgrade section, namely, from where traffic flow parameters mutate before the starting point of upgrade to where traffic flow return to stable state after the end of upgrade. Inspired by function zone of intersection and ramp, the influence zone of the upgrade section was defined from the perspective of traffic safety.

The influence zone of the upgrade section is the scope vehicles complete a series of complicated operation (reaction, acceleration, deceleration, car-following or overtaking etc.) because of the effect of road and traffic condition. The existence of upgrade sections leads to traffic flow in disorder. When the driver perceives the upgrade ahead from road traffic information such as slope warning signs, some may take corresponding measures, for instance, cars traveling in the outside lane may change to the inside lane and trucks may be prepared to speed up or remain constant speed, for getting through upgrade safely and smoothly. On upgrade, mixed traffic interfere with each other and they need to constantly adjust their speed in respond to inconstant traffic environment. In this period, the standard deviation of speeds in all vehicle types is far larger than that in a single type. Since trucks drive in lower speed, high-speed vehicle would have to follow them or pass by frequent lane changing, which may greatly lead to rear-end, sideswipe or other traffic accident. On the end of upgrade, vehicles need to driver a certain distance and gradually recover to a steady state. It can be seen that traffic flow on the influence zone is greatly divided into three stages, traveling relatively stable, disorder, restoring normal speed. Correspondingly, the influence zone can be divided into three parts: the upstream segment of starting point of upgrade, upgrade section, the downstream segment of terminal of upgrade.

Finding out the mutation of traffic parameters can roughly determine the influence zone of upgrade section. However, due to significant differences of traffic flow characteristics under different road and traffic condition, it need more time to carefully study one by one. Additionally, for different sections in a given influence zone, traffic flow characteristics are also greatly different. If the upgrade section can be parted into several sub-sections according to certain standard and basis, we can make further study on microscopic traffic flow characteristics of every sub-section, which will also put forward the basis for testing the rationality of existing climbing lanes on freeway.

5. Traffic safety improvement measures

Traffic safety issues on freeway upgrade section mainly attribute to vehicles’ speed difference, causing car-following or frequently overtaking. To improve road capacity and level of service on freeway upgrade section, the paper put forward some improvement measures as follows.

5.1. Optimization of horizontal and longitudinal alignment

Horizontal and longitudinal alignment plays a decisive role in vehicles’ operating speed, directly affecting road safety operation. Therefore, its index should be improved considering traffic safety on freeway upgrade section. In the stage of freeway planning and design, it need to choose reasonable slope and slope length by taking into consideration vehicles dynamic performance, the whole alignment, project investment and other factors and conducting a comprehensive research; properly adjust the longitudinal slope by adding structures such as tunnel in order to reduce the altitude difference and shorten the slope length.
5.2. The construction of climbing lanes

In fact, it is often difficult to optimize road alignment because of the limitation of the terrain, planning and engineering scale etc. Constructing climbing lane is a more feasible solution to traffic bottleneck on upgrade, currently which is the primary means to improve transportation security problem from the aspect of traffic safety and economy. When both traffic volume and trucks’ mixed rate are higher, it can improve cars’ driving freedom and increase the capacity of the section by separating trucks into climbing lane. Even so, it need to comprehensively consider effects of truck on traffic flow, the critical slope length, operation quality requirements, benefit to cost ratio and safety to determine whether setting climbing lane in the application.

5.3. Establishing perfect traffic safety facilities

The way is to consciously guide truck drivers to driving on the right lane or into climbing lane by setting up special traffic signs or markings, which is a more scientific method to improve capacity. It not only reduces the cost of the project, but also achieves the maximum protection of the environment and the idea of the "people-oriented". For instance, some countermeasures are generally be taken on upgrade to ensure vehicle’s operation safety, by setting slope warning signs, “No Passing Zone” signs, speed limit signs etc. To alert the driver to pay attention to the road alignment change, detours warning signs and chevron alignment signs are installed on roadway with steep curve and bad sight distance.

The selection of these measures must take into account the factors including grade, terrain, engineering cost etc. Moreover, it should ensure sight distance and road landscape coordination, so as to provide the drivers with a safe and comfortable driving environment.

6. Conclusion

The paper classified the upgrade section by liner combination form and whether constructing climbing lane, then generally analyzed traffic accident on freeway upgrade section, concluding that the main types of accident are rear-end, sideswipe and hitting guardrail or fixtures, the main factor attributing to vehicles’ speed difference. In addition, traffic flow characteristics were analyzed roughly and the influence zone of upgrade section was defined and divided into three parts, which laid good foundation for follow-up study on influence mechanism between microscopic traffic flow operation characteristics and traffic safety. Finally, some improvement measures were put forward to reduce traffic accident on freeway as soon as possible.

The limitations of the paper are that it didn’t propose the quantitative models between factors and traffic flow index and the method dividing the influence zone need to be in-depth considered and tested. Additionally, additional research is still needed to better understand the mechanism of traffic safety on freeway upgrade section.

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References

Junhua Wang, Shouen Fang, & Yuren Chen (2011). Traffic accident prevention technology research and demonstration on freeway (pp. 8-10). Shanghai: Tongji University press.


Qing xian Kuang (2010). Study on safety in the long slope of mountainous highway. Bachelor’s Thesis of South China university of technology, Guangzhou.

Sitao Hu, Qiaojun Xiang, & Yanyu Zhu (2013). Characteristics and causes of traffic accidents on freeway upgrade sections. Traffic information and security, 143-146.


Lu Tian (2009). Mountainous area freeway capacity and improvement measures of continuous upgrade sections research. Bachelor’s Thesis of South China university of technology, Xi’an.
