

Analysis of Interchange Exit Safety Technology

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Abstract: In order to improve the safety of the exit of expressway interchanges, the main problems and influencing factors of interchange exits are analyzed according to the number of traffic accidents at expressway interchange exits in China. Some suggestions and countermeasures are then put forward from the aspect of safety technology for future reference.

Keywords: Interchange; Exit safety; Safety guarantee

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1. Introduction

In view of urbanization, the construction of urban road network has been expanding in China. As an important part of the road network, interchanges are constantly increasing in scale and quantity. There are two types of interchanges: full interchange and semi-interchange, and the interchanges can be divided into three-level interchanges and five-level interchanges according to the traffic volume. However, there are still some problems in the design of the expressway interchange exits, such as the unreasonable design of the exit ramp and insufficient safety facilities. Accidents occur frequently at interchange exits. According to many statistics at home and abroad, accidents at the ramps of the expressway interchanges account for 30% of expressway traffic accidents. Among them, accidents on off-ramps are almost twice as high as on-ramps. Most of the research on the safety of interchange off-ramps at home and abroad discuss about different safety elements separately, failing to realize the synergy of multiple elements, and lacking the construction of the safety evaluation system and design method of interchange off-ramps^[1-6]. Interchanges play an important role in the transportation system. However, with the continuous increase in the number and scale of interchanges, the problems in their safety and security technologies are also emerging.

2. Case study

A high-speed section with a total length of 552 km was constructed in four sections, forming a road network structure consisting of “two hubs and four interchanges.” According to statistics, there were 4,495 traffic accidents in this section from 2012 to 2019, which caused 861 deaths and an economic loss of 290 million yuan. Among the traffic accidents, 97.9% of accidents caused human casualties; followed by mechanical damages such as motor vehicle collisions, tire blowouts, and vehicle rollovers, accounting for 32.3%, 13.2%, and 14.5%, respectively. There were many types of traffic accidents. Through the investigation and analysis of the accident scenes, it was found that the exit ramp of the expressway lacked safety facilities such as deceleration signs, speed limit signs and other warning signs, and these facilities were

set up after traffic accidents occurred. Without proper facilities and signs, driver will not be able to brake in time. In addition, due to the improper design of the exit ramp, the failure to set up emergency lanes and diversion lines, and insufficient speed control measures, drivers often speed. Because accidents were happening, the relevant departments renovated the interchange exits. According to renovation plan, the shape of the exit ramp will be changed from a “T” shape to an “L” shape. Vehicles turning left at the exit ramp of the interchange will directly enter the left-turn lane of the main line, and vehicles turning right will enter the right-turn lane of the main line. The linear design of the transformed interchange exit ramp is shown in Figure 1, which meets the requirements of the “Technical Standards for Highway Engineering” (JTGB01–2014)^[7].

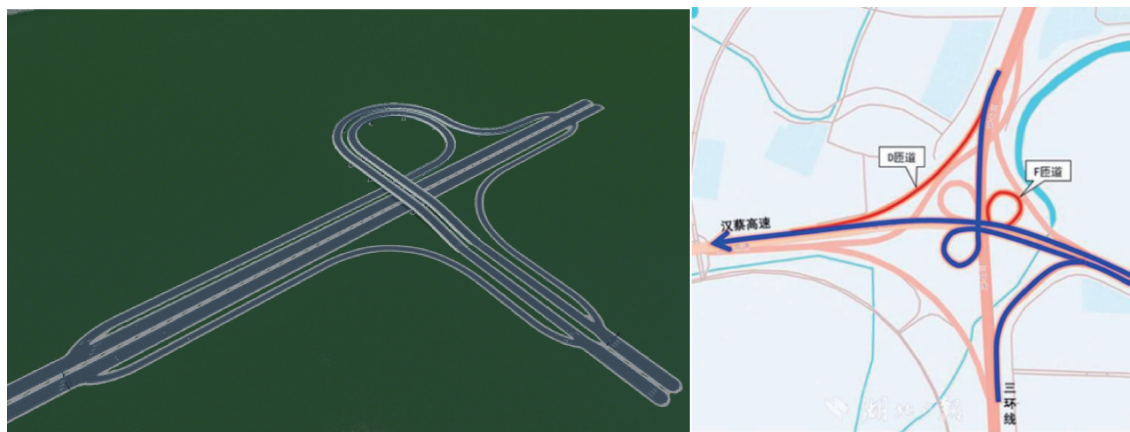


Figure 1 Exit ramps (left, “T” shape; right, “L” shape). Translation: (from left to right, top to bottom): Hancai Expressway, D ramp, F Ramp, Third-Ring Road

3. Problems and influencing factors in the safety design of interchange exits

3.1. Problems

Through the analysis of traffic accidents at interchange exits, several problems have been identified: First, the designed speed limit of the ramp does not match the actual operating speed. Taking this expressway as an example, the designed speed limit is 40 km/h, but the actual operating speed is about 70 km/h. Secondly, the horizontal and vertical alignment indicators of the entrance and exit are unreasonable. In cases where the angle is too small or too large, it becomes difficult for vehicles to make turns. Additionally, there are no warning signs when the ramp crosses the main road. The fourth problem is the improper design of emergency lanes. After analyzing the types and causes of expressway exit accidents in our country over the past ten years, it was found that the primary cause of such accidents is excessive speed when vehicles enter the ramp at the entrance and exit. This factor accounts for 81.0% of the total accidents at the entrance and exit points. The second leading cause is the improper operation of lane changes when vehicles enter the ramp, along with poor driving trajectories and the unreasonable placement of deceleration facilities. The road design (including alignment, line of sight, etc.) and condition of the driver (including fatigue driving, speeding, etc.) also contribute to traffic accidents.

There are three typical characteristics of a major traffic accident: (1) The number of traffic accidents that occur each year is roughly the same; in 2018 and 2019, with the rapid development of expressway construction and with the continuous growth of traffic flow, the probability of a major traffic accident has increased. (2) The main cause of a major traffic accident is speeding. Besides, due to factors such as road construction and increase in traffic flow have also contributed to the increase of traffic accidents. (3) Under

normal circumstances, it often takes a long time to resume normal driving after a major traffic accident.

3. 2. Influencing factors

There are many factors affecting traffic accidents at interchange exits, including drivers, vehicles, road environment, traffic management, and other factors^[8-11]. Among them, the driver's driving behavior is the most important factor. In addition, the road environment also contributes to the occurrence of accidents to a certain extent. As an important node between the interchange and the expressway, the interchange exit directly determines the traffic capacity and service level of the expressway. For ordinary roads, the traffic capacity of the interchange exit is low, but the probability of traffic accidents is high. In contrast, for expressways, the traffic capacity of the interchange exit is high, but the probability of traffic accidents is low. In addition, traffic management measures and traffic signs and markings also have a certain impact on the occurrence of traffic accidents. In short, there are many factors that affect the occurrence of accidents at interchange exits, which need to be considered comprehensively during the design stage.

4. Safety measures for interchange exits

In an interchange, the traffic flow from the main line and the ramp is heavily intertwined, and the exit experiences a relatively high volume of traffic. This complexity in traffic conditions contributes to an increased likelihood of traffic accidents. Therefore, the safety of exits is a very important issue in the design of interchanges. The exits should be designed according conditions like the speed and trajectory of the vehicles on the ramp, the traffic capacity and speed of the entrance and exit, the connection between the main line and the ramp, and the driver's behavior^[12-13]. For locations prone to traffic accidents, corresponding measures should be taken to reduce their safety risks. Based on our analysis, the safety measures for the exit of the interchange include improving the traffic signs and markings at the entrance and exit, improving the setting of deceleration lanes at the exit, and improving the speed limit of the exit road.

4. 1. Improve the exit deceleration lane setting

A deceleration lane should be set up before the exit ramp as the vehicle needs to decelerate before turning to enter the main line. At the same time, a lateral deceleration lane should be added before the ramp, and corresponding lateral deceleration lanes are set according to the vehicle speed. Due to the poor deceleration effect of the exit ramp, if raised pavement markers are set at appropriate positions (such as 20–90 m) from the ramp, with less distance between the markers, drivers will be able to feel the driving speed. Speeding up gradually and slowing down subconsciously is more beneficial to driving safety and can effectively reduce the accident rate. Longitudinal bumps can also be placed before the exit of the interchange to slow down the speed of vehicles and improve driving safety.

4. 2. Strengthening the speed limit management of exit roads

Speed limit signs should be placed at the exit of interchanges, and the speed limit value should be determined according to the road grade and the specific conditions of that section. The drivers should drive according to the speed limit and should be fined or punished if they exceed the speed limit.

4. 3. Strengthening the management of relevant units and personnel

Relevant units and personnel should place greater emphasis on and implement effective measures to ensure the traffic safety of the interchange exit. Corresponding safety measures should be taken according to the characteristics of the traffic accidents at the interchange exits to reduce the possibility of traffic accidents. In the design of exits, it is crucial to strengthen the management of facilities along the road, as well as signs and markings. Additionally, efforts should be made to enhance the capability to monitor and predict

the traffic behavior and psychological state of drivers.

4.4. Improving the placement of traffic signs and markings so that drivers can identify the locations of the exit accurately

Proper signboards, deceleration signs, and other indicators should be strategically placed at interchange exits. Proper markings should be drawn on the exit section of the interchange and they should be adjusted accordingly. It is important to make sure that the markings are coordinated with the ground markings. The speed limit at ramp exits and the distance should be reduced to allow drivers to decelerate, brake, and stop in time, so that there is enough space between vehicles. This can be achieved by controlling the speed of the vehicles at the off-ramp or extending the length of the off-ramp. Early warning facilities such as variable speed limit signs and slow-down signs should be placed to remind drivers to slow-down or stop in time to avoid dangerous situations. It is important to use guidance signs, warning signs and other means to guide vehicles into the main lane. Traffic management facilities such as reversible lanes should be provided to ensure the orderly passage of vehicles.

4.5. Location of the exit

Incorrect judgment of the intersection's direction by drivers can lead to vehicle collisions, which significantly disrupts the normal operation of the interchange exit. Especially for the continuous exits on the main line, because the signs are often complicated, so it is difficult for drivers to determine the direction that they want to go to in time. Therefore, it is best to not design multiple exits or intertwined entrances and exits on the main road. In view of the left and right turnings of the four road hubs, an exit in one direction should be formed on the main line, and the distance between exits in two directions should comply with the provisions of the "Design Rules for Highway Interchanges" (JTG/T D21-2014), so that drivers who need to turn can leave the main line from the exit in one direction after slowing down. After that, drivers can turn left or right in the ramp diversion in one direction. With this method, the driver can only make one decision at each exit or ramp intersection, and can only go one way, which gives them more time to think and react.

4.6. Traffic organization and management

(1) Vehicles in different directions should be strictly distinguished to avoid traffic accidents. The direction of the ramp exit should be clear to prevent traffic accidents. (2) A comprehensive assessment should be carried out on of the ramp's traffic capacity, operating speed, and plane alignment. Soft isolation should be used for ramps with small traffic capacity, high speed limit requirements, or poor alignment. (3) If the traffic flow on the main line is affected by vehicle lane changes, etc., hard isolation or soft isolation can be installed at the entrance of the exit ramp; (4) Traffic control should be done properly and some vehicles should be diverted to other roads. Stop and slow-down signs should be set up near the exit to ensure that there is enough space for vehicles to park safely on the road near the exit. (5) Toll plazas can be set up before the exit as needed. The toll plaza should be able to guide vehicles to enter and leave the auxiliary road, so as to reduce the interference of vehicles changing lanes on the traffic flow of the main line. (6) The signs and markings near the exit should be improved.

5. Conclusion

In terms of design, a comprehensive safety assurance system should be constructed with people, vehicles, roads, and the environment as the major elements. In terms of operation management, the active control of vehicles can be achieved by building a complete information system and early warning mechanism. From

the perspective of road operation, the efficiency of road traffic can be improved by setting signs, lines, warnings and other facilities, and optimizing traffic conditions.

Unreasonable positions of interchange exits will cause drivers to change lanes frequently on the ramp, which leads to traffic accidents. (2) Unreasonable ramp alignment will cause the vehicle move slowly, and it might lead to vehicle collisions. (3) The safety facilities at the interchange exits are not ideal, so is the traffic organization and management system, which is also the reason for the traffic accidents. Therefore, in order to ensure the safety of vehicles at the exit of interchanges, safety facilities should be placed strategically. Besides, the research on the safety technology for interchange exits should be strengthened.

Disclosure statement

The authors declare no conflict of interest.

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