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Strategies for Ramp Route Design of Highway Interchange

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Abstract: The rapid advancement of urban transportation in modern China has driven urban economic developments. However, the progressively congested traffic conditions have affected the productivity and daily life of the people. To mitigate the congestion problem, necessary road designs should be implemented along the highways, for example highway interchanges. The application of highway interchanges in past cases have proven to effectively avoid traffic flow conflicts, reduce highway traffic congestion, and reduce traffic accidents, this is conducive to ensuring the safety and efficiency of the highway. In order to improve the safety and convenience of urban road traffic, this paper analyzes the strategy of using interchange ramp route designs for highway traffic.

Keywords: Interchange ramp; Route design; Variable speed lane

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1. Introduction

Due to increased congestion at the intersection of high-grade roads and arterial roads, the use of interchanges as the entrance and exit of urban expressways has received more attention due to its potential to improve China's urban highway transportation. Effective solutions will increase the driving speed and reduce the incidence of traffic accidents, thus when carrying out interchange design work, it is important to improve the level of ramp design [1]. A ramp is a connecting lane specially set up for the turning traffic flow of two intersecting main lines, it acts as the acceleration and deceleration transition section for vehicle speed changes. The selection and design of the ramp can affect the overall use of the road, different forms of ramps can be combined to form different interchange shapes to meet the needs of highway interworking developments.

2. Design of the ramp

2.1. The form of the ramp

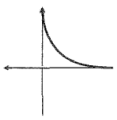
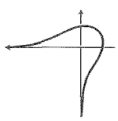
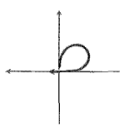
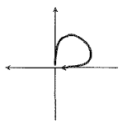
The current form of highway interchange ramps includes two aspects: the left–turn ramp to meet the left turn traffic demand, and the right–turn ramp to meet the right turn traffic demand. Due to China's right-hand traffic practice, generally when exiting the arterial road the using a right-turn ramp, a 90° right turn will allow the driver to directly enter the right side of the intersecting road. The entire driving process is more convenient and causes less interference to traffic in other directions within the intersection range. Vehicles making a left turn generally need to turn 90–270° before entering another road, during this process, there are intersections, conflicts with the traffic flow (going straight or turning right), and sometimes a flyover bridge may be needed. Currently, the forms of left-turn ramps that are commonly used include

direct, semi-direct and indirect interchanges, the scale and form of an interchange are usually restricted and closely related to the left-turn ramp. The shape and position of the left-turn ramp can be flexibly changed according to the actual situation, as different forms can be used to gradually form different interchanges. All interchanges are formed by combining/deforming the above three forms. Generally, the application of direct interchanges is suitable for when there is a large number of left-turning vehicles, whereas semi-direct interchanges should be set according to the actual left-turning traffic volume and terrain characteristics. If the transfer volume is relatively small, the indirect type can be used and the turning part can be set as an arc, drop shape or ellipse [2].

2.2. The speed of the ramp

The ramp functions as the entrance and exit of vehicles into the main traffic line, thus the traffic volume must be smaller than the main line, and is limited by various factors such as terrain, scale, land use, function, etc. The driving speed of the ramp part should also be slower than the main line, however it cannot be too slow. That is because China's "Urban Road Code" and "Highway Route Design Code" have clearly stipulated that the speed of the ramp should not be lower than 60% of the main line speed, and in special cases not lower than 50%. This standard is set to avoid a large speed gradient between the ramp and the main line to prevent congestion and traffic accidents. The speed of the ramp part should also be consistent with the actual traffic flow and traffic flow direction. For ramps with large traffic volume, the speed should be appropriately increased to increase the capacity of the ramp part [3]. The regulations on the design speed of the ramp are clearly stipulated in the "Detailed Rules for the Design of Highway Intersections" (JTG/T D210214), as shown in **Table 1** [4].

Table 1. Design speed range of the basic section of the ramp

Ramp type		Direct connection		Semi-inline		Circular ramp	
		Standard type	Variant	Inside turn	Outside turn	Standard type	Variant
General interchange	Design speed (km/h)	40–60	30–40	/	40–60	30–40	30–40
	Ramp form			/			
Hub interchange	Design speed (km/h)	60–80	50–60	60–80	40–60	40	40
	Ramp form						

3. Linear design of the ramp

3.1. Design of variable speed lanes

There are two types of speed-changing lanes: direct and parallel. In most cases, the acceleration lane uses the parallel type, whereas the deceleration lane has to use the direct type. The overall length of the deceleration lane can have a direct impact on the effect of vehicle deceleration. According to the actual driving speed of the vehicle, the deceleration process can be divided into three different stages: In the first stage, after the driver recognizes the direction and enters the gradual road section, the vehicle is still driving at a constant speed at the initial speed of the diversion point; in the second stage, the vehicle enters the deceleration lane and is affected by inertia. The driver needs to gradually decelerate with the help of driving resistance while releasing the accelerator. Usually, the initial deceleration time is about 3s, and the deceleration rate is relatively small; in the third stage, the vehicle enters the deceleration lane, and the drivers behind can already fully understand the ramp speed limit requirements, and gradually implement any necessary deceleration to the ramp design speed.

There is also a certain difference in the speed of vehicles in the diversion area. Based on the secondary deceleration theory, the deceleration process of ramp vehicles can be analyzed and divided into three stages: During the first stage, the vehicle enters the triangular gradient and then the deceleration lane at the initial speed of the diversion point; at the second stage, the initial deceleration starts with the help of driving resistance and the car engine; as for the third stage the final deceleration operation is performed with the help of the car brake [5].

3.2. Longitudinal section design

When designing the longitudinal section of the ramp, it is necessary to comprehensively consider various factors such as geology, topography, clearance, economy, and safety to ensure that the design is rational. Linear combination can be used to optimize the relationship between the main line of the ramp, the longitudinal slope, and the road to be crossed. This ensures the balance and coordination between various indicators of the plane alignment and longitudinal section alignment, which leads to a smooth and continuous three–dimensional alignment of the longitudinal section of the ramp.

However, because the actual range of ramp longitudinal section design is not consistent with the plane line length, it is not possible to fully refer to the plane line design measures. Normally, the starting point of the longitudinal slope of the ramp is at the end of the vehicle diversion point, and the ending point is at the end of the vehicle merging point. The longitudinal slope and transverse slope of the variable speed lane before the ending point changes with the transverse slope and longitudinal slope of the main line. When determining the starting point and ending point of the longitudinal slope and transverse slope of the ramp, the actual situation of the transverse slope and longitudinal slope of the main line must be fully considered, and the synthetic slope method or the average gradient method should be used to calculate the transverse slope and longitudinal slope.

When designing the slope of a single ramp, care should be taken to ensure that the minimum slope length of the ramp is compliant with construction requirements. As for the vertical curve of the ramp, the minimum length and the minimum slope should also be within construction requirements. Towards the end of the ramp, the radius of the vertical curve should be increased to ensure that the driver can have sufficient front view distance, which provides additional safety.

3.3. Cross-sectional design

Highway ramps consist of four parts: the lane, the hard shoulder, the curb strip, and the soil shoulder. In general, the width of the cross-sectional diagram of the ramp should be based on the traffic volume. When the traffic volume is not large, a single lane with a width of 9 m is used. According to the length of the

ramp, it can be widened for overtaking. If the traffic volume is large, a one-way two-lane ramp is required, and the general roadbed width is 10.75 m or 12.5 m. Some directions that require two-way driving can adopt the mode of opposite double lanes, however the two-way lanes should be separated, and the width of the roadbed is generally 15 m. If the lane is a mixed vehicle lane, the width of the non-motor vehicle part should be calculated according to the actual traffic volume [6].

3.4. Design of ramp connection

The ramp connection is the connection area between the two ends of the ramp and the main line. This part includes the auxiliary lane, the upper lane of the variable speed vehicle, and the entrance and exit of the ramp. Previously, if you were behind a straddle structure, you had to keep at least 150 m away from the structure. Concurrently, to improve vehicle deceleration efficiency, the exit position should be set in the uphill area, while downhill entrance positions can improve the acceleration efficiency of the vehicle. In addition, before the ramp merges into the main line, the triangular area where the main line (100 m) and the ramp (60 m) are located should be visually clear, and a variable speed lane should be set at this position [7].

3.5. Ramp superelevation design

In order to keep the project scale of the interchanges within a reasonable range, the horizontal curve index within the design range is usually low. Because superelevation will affect the safety of driving, full emphasis must be given when selecting the superelevation value and determining the superelevation transition mode [7]. In case of normal superelevation transition, a superelevation transition section should be set for the middle part of the straight line on the ramp. The superelevation circular curve and the length of the transition section is determined by the maximum superelevation value, the superelevation gradient rate, the position of the rotation axis, and the design of the ramp.

As a whole, the focus of the superelevation transition section design work mainly includes three aspects: (1) If the superelevation transition section contains a transitional curve, the superelevation transition section as a whole should be in the transitional curve. If there is no need to set a transitional curve, within the range of the superelevation transition section, one–third to one–half of the length should be in a circular curve, and the rest can be a straight line. If there is a connection between two circular curves, a transitional curve should be set in between and combined with the setting of the superelevation transition section as much as possible; (2) When the superelevation gradient is selected, the part of the regular road section on the ramp and the part with basically no change in width shall be adjusted according to the relevant requirements. However, if the location of the toll booth or the width of the ramp itself changes significantly when selecting the gradient rate, the influence of the width change must be taken into account, especially if there is a high gradient in the ramp. In order to improve drainage [8], an ultra-high gradient rate should be selected. (3) Superelevation transition methods mainly include straight line method and cubic parabola method, the straight line method is less complex but more rigid, and will cause the edge of the road to appear too distorted. Thus, the method is mainly used for the beauty, safety and smoothness of driving. In most cases, the method of cubic parabolic transition is used instead [9].

3.6. Ramp lighting design

According to relevant research, if the night lighting effect of the highway ramp is good, the road use efficiency can be increased by one-fourth to one-third, which can also generate higher economic benefits. From a practical point of view, not only can optimizing lighting design improve the safety of road driving at night, it can also increase the overall infrastructure standards of the city. Lighting design should be considered for the part of the interchange ramp where there is a need for lighting. The most commonly used

lamps include sodium lamps, high-pressure mercury lamps, etc. The height of the lamps should be set according to the road width and layout method, usually 6–8 m is appropriate. The installed height of lamps has great impact on the distance between lamps. In general, the distance between adjacent luminaires should be set at 25–30 m, the cantilever length of luminaires should be 2–4 m, the elevation angle should be within 15°, and the illuminance and uniformity of the lamps should also be reasonably controlled [10].

3.7. Landscape design

According to the "Highway Route Design Code", when designing the ramp route, attention should be paid to the landscape of the relevant location. The location landscape can be incorporated with the linear layout of the ramp, which provides beautification while still protecting the environment. Because the overall shape of the interchange is mainly a spatial form, it is necessary to adopt the combination of flat and vertical planes for landscape design. While doing so, care should be taken to avoid disrupting the natural ecological landscape to improve the overall aesthetic level of the landscape [11].

4. Conclusion

As a summary, the highway interchange ramp is an important component in the process of road traffic development because it has a profound impact on the convenience, effectiveness, and safety of traffic. Highway interchanges are important areas for traffic to turn, gather and evacuate, it is also one of the main factors affecting the smoothness of traffic. Therefore, during the ramp design process, it is necessary to ensure that the plane, longitudinal section, cross section, ramp, connecting parts, ancillary works, and overall shape are all in reasonable condition. This will effectively improve the application of the ramp part, while also ensuring the convenience and safety of road traffic.

Disclosure statement

The author declares no conflict of interest.

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