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Design Strategies for Reconstruction and Expansion of Insufficient Clearance Sections in Highway Interchanges

Shuai Li*, Zhipan Yang, Jianchao Xu

China Merchants Chongqing Communications Technology Research & Design Institute Co., LTD., Chongqing 400067, China

**Author to whom correspondence should be addressed.*

Abstract: Combining practical engineering projects, this article analyzes the design strategies for the reconstruction and expansion of insufficient clearance sections in highway interchanges. This includes an overview of the project, a comparison of design options for insufficient clearance in interchanges, and the main design strategies for reconstruction and expansion. It is hoped that this analysis can provide a reference for the design of such road reconstruction and expansion projects.

Keywords: Highway; Interchange; Insufficient clearance; Reconstruction and expansion design; Design scheme

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1. Introduction

In the design of highway interchange reconstruction and expansion, insufficient clearance sections are a design challenge. Based on this, designers should combine the actual project overview, compare and select various schemes to determine a reasonable design scheme. Finally, according to the determined design scheme, implement the reconstruction and expansion design with reasonable strategies. This can ensure the rationality of the reconstruction and expansion design and solve the problem of insufficient clearance.

2. Project overview

This study focuses on a highway interchange reconstruction and expansion project. The existing interchange of the project is located on a hill. According to the adjacent line reconstruction and expansion plan, the construction unit needs to build a new interchange on the highway connection line. However, after design analysis, it was found that after the completion of the new interchange, there is insufficient clearance between the two interchanges.

Therefore, before the construction of the new interchange, the construction unit needs to implement reasonable reconstruction and expansion treatment for the project, expanding it from the original three-way interchange form to a four-way interchange form. This article mainly analyzes the design strategy of the reconstruction and expansion of this road section.

3. Comparison and selection of interchange clearance design schemes

3.1. Clearance design supported by signs and markings

According to the current design requirements of this road section, due to the insufficient spacing between the existing interchange and the newly built interchange, all exit preview signs cannot be set, resulting in incomplete road information display. Based on this, designers need to set preview signs at a distance of 500m from the newly established interchange, and all other signs should be set in front of the previous existing interchange to meet the actual prediction and indication requirements. In this case, designers only need to set a preview sign within the insufficient clearance section. When a vehicle enters from the entrance of the previous existing interchange, there will be only one opportunity to read the exit information. If the driver misses it, the vehicle will not be able to reach the exit smoothly and will have to quickly adjust the lane, which can easily cause traffic confusion [1]. To avoid this problem, designers need to reserve a certain distance for drivers to discover and read the exit signs. According to the 3-second theory of determining travel time, when the car speed is 120km/h, the driving distance between seeing the sign and successfully reading it is about 100m. Therefore, if only one exit preview sign is set, the minimum distance between it and the new interchange should be controlled to 600m.

3.2. Clearance design supported by traffic theory

The so-called minimum traffic theory distance refers to the minimum driving distance for the driver of the inner lane vehicle to react and complete relevant operations immediately after reading the exit preview sign. Due to differences in the driver's own state, vehicle performance, and other conditions, different scholars have constructed different models for calculating this clearance. Based on this, the designer assumes a worst-case scenario where a vehicle enters from the ramp entrance. Due to unfamiliar road conditions, the driver may change lanes to the inner lane. When it is found that the exit is located on an adjacent ramp, it is necessary to quickly change lanes to the outer side [2]. In this case, the driving distance during the process of vehicle entry, lane change, re-lane change, and exit can be used as the minimum clearance between adjacent interchanges.

3.3. Clearance design supported by safe lane changing

When vehicles change lanes from the inner lane to the outer lane, designers can introduce traffic flow and probability theory based on a comprehensive consideration of parameters such as the number of lanes and vehicle speed. This can be used as a basis to establish a probabilistic relationship model between vehicle exit distance and safe lane changing [3]. Through this model, it can be concluded that as the clearance of the interchange increases, the safety of lane changing increases linearly, and the threshold for safe lane changing needs to be controlled at 0.95.

3.4. Comparison and determination of clearance design schemes

Through a comparative analysis of the above three clearance design schemes, it is found that the clearance design scheme supported by signs and markings did not fully consider special situations such as lane changing of inner vehicles during the design process. Therefore, the results obtained are relatively conservative and need to be properly adjusted and optimized through other methods. The extreme conditions assumed in the clearance design scheme supported by traffic theory generally do not occur, so the final designed minimum clearance will be much larger than the actual demand. The clearance design scheme supported by safe lane changing, effectively combines relevant theories and probabilities in the process of traffic operation. The various factors considered in the design are compatible with the actual traffic operation of the highway, and various factors such as driving speed, vehicle performance, and driver psychology are also comprehensively considered. Therefore, this scheme is more objective and scientific [4]. Based on this, in this project, the designer decided to design based on the clearance design scheme supported by safe lane changing.

4. Main expansion design strategies for insufficient clearance of interchanges

For the problem of insufficient clearance of interchanges in this project, the designer has determined the following design strategies according to different situations and design requirements during the specific renovation and expansion design.

4.1. Expansion through the addition of auxiliary lanes

Before the auxiliary lane is set up, vehicles will merge into the main line under conditions where the driving speed and lane matching are not ideal, which can easily lead to traffic conflicts. If an auxiliary lane is added at the exit of the interchange to connect two interchanges with insufficient clearance, when the vehicle exits the interchange, it can adjust its driving speed on the auxiliary lane. When there is a safe gap in the inner lane, it can exit in a timely manner, thereby significantly reducing the probability of traffic conflicts [5]. For the auxiliary lane, when setting it up, the designer needs to reasonably determine the length of the auxiliary lane based on various factors such as the actual traffic capacity in the interlaced area, the running time of the split and merge, and the distance of the advance sign.

During specific operation, the main purpose of setting this auxiliary lane is to alleviate or reduce the adverse disturbances caused by the split and merge traffic in the main traffic. If the length of the auxiliary lane is continuously increased, there will be no traffic flow interleaving in the middle, but the two ends will still form a split and merge traffic state. According to the relevant provisions in the “Detailed Rules for the Design of Highway Reconstruction and Expansion” JTG/TL11-2014, if the length of the interlaced area reaches more than 760m, the traffic flow can achieve a complete conversion of split and merge. Under the condition of continuously extending the interlaced area, the adverse effects of this kind of traffic split and merge on straight traffic will continue to weaken [6]. Based on this, the designer initially designed the minimum length of the auxiliary lane in this project as 760m.

According to the relevant provisions in the “Detailed Rules for the Design of Highway Interchanges” JTG T D21-2014, when designing the main line of an interchange in the form of a two-way six-lane, if the number of ramp lanes is increased, the minimum length of the auxiliary lane should also be appropriately adjusted. After comprehensive consideration of various factors, the finally determined minimum length of the auxiliary lane is slightly larger than the initial design value. **Table 1** shows the design parameters of the minimum length of the auxiliary lane based on the designed speed of the main line in this project:

Table 1. Design parameters of the minimum length of the auxiliary lane based on the designed speed of the main line in this project.

Serial number	Main road design speed	General length of auxiliary lane	Minimum length of auxiliary lane
1	80 km/h	1000m	800m
2	100 km/h	1100m	900m
3	120 km/h	1200m	1000m

4.2. Expansion through the setting of collector-distributor roads

When the clear distance of the interchange is insufficient and auxiliary lanes cannot be reasonably set according to the above design requirements, designers can set collector-distributor roads for it. In this type of roadway, there is no straight traffic flow in the interweaving area, and only the traffic flow at the ramp exit and entrance interweaves with it. Typically, such roadways should be designed based on the actual technical requirements of the ramp and the operating speed of the vehicles. Because its design speed is relatively low, the efficiency of vehicle interweaving also needs to be reasonably reduced. Regarding this situation, there is no clear provision for its length design in the "Detailed Rules for the Design of Highway Interchanges." Therefore, in this design, the designer mainly analyzes the minimum length of the collector-distributor road based on road capacity and service level.

Firstly, the length of the interweaving area is reasonably determined. During the specific design, the designer divides the traffic flow interweaving situation into the same-side interweaving area and the opposite-side interweaving area. The interweaving intensity coefficient is estimated based on the vehicle lane-changing rate, thereby making a scientific analysis of vehicle density. Then, the safe operation level of the designed road segment is reasonably evaluated based on vehicle density. In this mode, the distance between the merging and diverging points is the length of the interweaving area. The larger the length value, the longer the lane-changing distance for vehicles in this area, and the smaller the vehicle conflict density. This can effectively improve the traffic capacity of the road segment [7].

Secondly, the length of the interweaving area on the collector-distributor road is reasonably determined. According to the relevant provisions in the "Detailed Rules for the Design of Highway Interchanges", designers can use the standard of variable speed lanes as a basis to make scientific designs for the connection between collector-distributor roads and main roads. Based on the actual situation of the project, the vehicle speed on the collector-distributor road needs to be 20km/h lower than that on the main road. To ensure that vehicles exiting the collector-distributor road can stably enter the ramp, the designer takes the coordination of operating speeds as a basic principle and controls the difference between the driving speed of ramp vehicles and the driving speed of collector-distributor road vehicles to be 20km/h or more.

Based on the above design ideas, the designer performs a trial calculation of the traffic flow in the interweaving area on the collector-distributor road. When the length of the preliminary design value is trial-calculated to be 760m, and if its traffic density reaches 18–25pcu/km/ln, the trial calculation can be terminated. To further simplify the calculation and analysis process, in this design, the designer assumes that the ramp at the exit and entrance of the collector-distributor road has the same design speed. Under this design mode, the designer's trial calculation results for the length of the interweaving area on the collector-distributor road are shown in **Table 2**.

Table 2. Trial calculation results for the length of the interweaving area on the collector-distributor road in this design

Serial number	Design speed of collector-distributor lanes	Design speed of ramps	Length of weaving area on collector-distributor lanes		
			Two-entry and two-exit	Two-entry and one-exit	One-entry and one-exit
1	40 km/h	30 km/h	70m	90m	--
2	40 km/h	40 km/h	--	--	--
3	50 km/h	30 km/h	60m	50m	130m
4	50 km/h	40 km/h	150m	90m	580m
5	50 km/h	50 km/h	--	--	--
6	60 km/h	40 km/h	110m	70m	150m
7	60 km/h	50 km/h	200m	--	410m
8	60 km/h	60 km/h	--	--	730m
9	70 km/h	50 km/h	150m	80m	190m
10	70 km/h	60 km/h	250m	100m	280m
11	70 km/h	70 km/h	--	--	400m
12	80 km/h	60 km/h	200m	85m	180m
13	80 km/h	70 km/h	320m	110m	240m
14	80 km/h	80 km/h	--	130m	320m

The trial calculation results show that as the design speed of the ramp increases, the length of the interweaving area also increases, whereas as the design speed of the collector-distributor road increases, the length of the interweaving area decreases. Under the conditions of a double-entry and double-exit collector-distributor road, the traffic density will reach above 36pcu/km/ln. Therefore, this type of collector-distributor road should be avoided in the design. If the traffic volume is relatively large, a variant form of double-entry and double-exit ramp can be considered in the design of the collector-distributor road. This type of collector-distributor road can reasonably avoid traffic interweaving on the main road and achieve reasonable changes in the merging sections of the entrance and exit. At the same time, in this mode, vehicles will reasonably change lanes to the outermost lane before exiting from the main road, which is completely consistent with China's road traffic habits. **Figure 1** shows a schematic diagram of the variant form of double-entry and double-exit ramp for the design of collector-distributor roads.

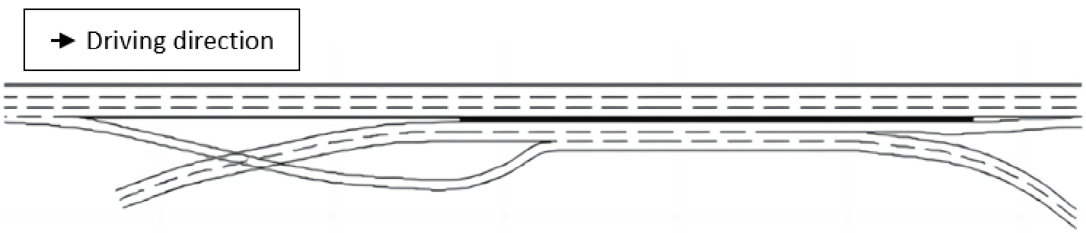

Figure 1. Schematic diagram of double-entry and double-exit ramps in a variant form during the design of collector-distributor lanes

4.3. Expansion through interconnected ramps

If the clear distance between two adjacent interchanges is very small and the length of the weaving area is limited, and the auxiliary lane setting method and the collector-distributor lane setting method cannot meet the actual traffic demand, designers can set up a compound interchange route through interconnected ramps. In this mode, there will be a relatively large number of exits on the designed compound interchange route. To achieve effective merging between exits and entrances, designers can combine actual conditions and adopt several connecting ramps to implement connection processing, thus providing convenience for vehicle merging and diverging on other ramps and effectively reducing the disturbance caused by vehicle merging and diverging to the straight traffic flow in the insufficient clear distance section [8].

4.4. Expansion through multi-way intersection merging

If there is a serious insufficiency of clear distance in the interchange and a new road needs to be connected on this basis, designers can carry out intersection merging design through multi-way intersection merging [9]. Because the overall shape of this kind of interchange is relatively complex and there is no standard form for reference, designers should reasonably select the form of left-turn traffic routes during specific design. For crossroads in the form of dual lanes, designers can design multi-way intersecting routes as annular. This can reasonably simplify the traffic flow pattern and make the layout of the interchange sufficiently compact to meet the actual traffic demand of the project [10].

5. Conclusion

In summary, with the continuous expansion of modern transportation, many existing highways need to be renovated and expanded to meet their actual traffic flow carrying demand. However, when renovating and expanding the main line of existing highways, if there is insufficient clear distance in the interchange, designers need to combine the specific project overview, conduct a comprehensive analysis of various factors, and develop a sufficiently scientific and reasonable renovation and expansion design plan. At the same time, reasonable strategies should be adopted to implement the renovation and expansion design according to the different situations and transportation demands of the insufficient clear distance locations of the highway interchange. Only in this way can the problem of insufficient clear distance be effectively solved, and the renovation and expansion design of the highway can be reasonably optimized to meet the actual vehicle traffic demand.

Disclosure statement

The author declares no conflict of interest.

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