Research on Highway Route Optimization Design and Safety Performance Improvement under Heavy Traffic Conditions

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Abstract: With the development of economy, heavy-haul traffic plays an increasingly important role in highway transportation, which has a significant impact on highway routes. Therefore, it is urgent to study related optimization design and safety performance improvement. This paper aims to analyze the theoretical basis of heavy traffic and highway route through theoretical research, construct the theoretical system of highway route optimization design under heavy traffic, and put forward the optimization strategy based on safety performance improvement. During the research, the optimization design theory of plane, longitudinal section, cross section and line sight distance is discussed in depth, starting from vehicle dynamics, pavement structure response, traffic flow characteristics and so on. By reasonably increasing the radius of horizontal curve, controlling the gradient of longitudinal slope, enhancing the bearing capacity of pavement and optimizing the traffic flow organization, the highway route design can be effectively optimized and its safety performance can be improved. This study provides theoretical basis and technical guidance for heavy traffic highway construction.

1. Introduction

With the rapid development of economy and the continuous growth of freight demand, the position of heavy-duty traffic in highway transportation system is increasingly prominent. With its advantages of large capacity and high efficiency, heavy-haul traffic has transported a lot of materials for economic construction, which has effectively promoted the development of industry, energy and many other fields [1]. However, heavy traffic has brought great pressure to highway infrastructure. Heavy-duty vehicles that frequently pass by are much heavier than ordinary vehicles, which greatly increases the load borne by the road and accelerates the damage process of the road, such as cracks and ruts on the road surface, which not only affects the service life of the road, but also poses a serious threat to driving safety [2].

From the development course of highway construction, the early highway design mainly focused on ordinary traffic flow and conventional load, and the adaptability of heavy traffic was not considered enough [3]. However, nowadays, the heavy-haul traffic flow is constantly rising, and the original design concept and method can no longer meet the demand. If the traditional design is continued, the service life of the highway will be greatly reduced, the maintenance cost will increase greatly, and the probability of traffic accidents will also increase significantly [4]. Therefore, in order to ensure the sustainable development of highway and meet the increasing demand of heavy-haul traffic, it is urgent to optimize the highway route design and improve its safety performance [5]. With the development of traffic engineering, material science, mechanics and other disciplines, it provides new theoretical and technical support for solving the problems faced by highway routes under heavy traffic [6]. It is expected to find a more effective optimization design scheme through interdisciplinary research methods and comprehensive consideration of many factors such as heavy traffic characteristics, highway structural mechanical properties and driving safety.

Based on the existing theories and technologies, this study aims to deeply analyze the influence of heavy traffic on highway routes, build a scientific and reasonable theoretical system of highway route optimization design, and put forward practical safety performance improvement strategies to promote the high-quality development of highway transportation.

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2. Heavy traffic and highway route related theory

As a special type of highway transportation, heavy-haul traffic has remarkable characteristics. Its vehicle load far exceeds that of ordinary vehicles, with large axle load and large quantity, and the transported goods are usually high-weight materials such as coal and ore. These characteristics lead to a huge difference between the way and intensity of its action on highways and ordinary traffic [7]. With the acceleration of industrialization and urbanization, the demand for heavy-duty transportation is on the rise, and its development is not only driven by economic development, but also closely related to industrial layout.

Highway route design is a complex system engineering with solid basic principles. According to the natural conditions such as topography, geology and climate, combined with the traffic demand such as traffic flow and driving speed, it is necessary to reasonably determine the plane, longitudinal section and cross-sectional alignment of the route. Plane alignment design is related to the route direction and curve setting, aiming at ensuring the smooth and safe driving of vehicles. The linear design of longitudinal section determines the slope and vertical curve of the route, which has great influence on the dynamic performance and driving stability of the vehicle. The linear design of cross section involves the width of road surface, the slope of road arch, etc., which is related to the comfort and drainage function of vehicles.

Safety performance occupies a core position in highway route design. It covers many aspects, including the stability of the vehicle during driving, the protection of the driver's sight distance, and the coordination between the route and the surrounding environment [8]. The standard of safety performance is reflected by a series of indicators, such as the radius of the least square curve, the maximum longitudinal slope, and the safe sight distance. These indicators are summarized according to the principles of traffic engineering and a lot of practical experience, so as to ensure that the road safety needs are fully considered in the design stage.

3. Optimal design of highway route under heavy traffic

(1) Optimal design of plane alignment

In the heavy traffic environment, the plane alignment design has a far-reaching impact on the stability and safety of vehicle driving. Due to the large mass and strong inertia of heavy-duty vehicles, it is necessary to have a larger turning radius when driving in corners. Therefore, the theory of plane alignment optimization design emphasizes that the radius of plane curve should be reasonably increased according to the dynamic characteristics of heavy-duty vehicles [9]. This theory requires that in the route planning stage, the terrain conditions and engineering feasibility should be fully considered, and the horizontal curve radius should be as large as possible to reduce the centrifugal force of vehicles driving in corners and reduce the risk of side slip and overturning.

Under heavy traffic, the transition curve should be accurately designed according to the speed, load and driving characteristics of the vehicle to ensure that the vehicle can smoothly transition from a straight line to a curved line. The theory of optimal design advocates the adoption of a transition curve that conforms to the vehicle trajectory, such as a cubic parabola transition curve, which can better adapt to the speed change and centrifugal force transition during the driving of heavy-duty vehicles and improve the comfort and safety of vehicles.

(2) Optimization design of longitudinal alignment

For heavy traffic, the key of longitudinal alignment design lies in reasonable control of slope and vertical curve. The climbing ability of heavy-duty vehicles is relatively weak. Excessive longitudinal slope will increase the engine load of the vehicle, resulting in insufficient power or even flameout, and at the same time aggravate the wear of the brake system, affecting brake safety [10]. Therefore, the theory of longitudinal optimization design advocates reducing the longitudinal slope as much as possible under the premise of satisfying the terrain conditions and engineering economy, and generally controlling it at a low level to ensure that heavy-duty vehicles can climb the slope smoothly.

When a heavy-duty vehicle is driving, its center of gravity is high, and the radius of vertical

curve is too small, which will cause great impact and bump when the vehicle is driving, and affect the life of vehicle parts and the stability of goods. Based on this, the theory of longitudinal alignment optimization design emphasizes that the radius of vertical curve should be reasonably increased according to the factors such as the driving speed and the height of gravity center of heavy-duty vehicles, so as to ensure that the vehicles can keep stable when driving in the vertical curve section and reduce the adverse effects on vehicles and goods.

(3) Optimal design of cross-section alignment

The bearing capacity and drainage demand of pavement structure should be fully considered in the linear design of cross section under heavy traffic. Due to the heavy axle load of heavy-duty vehicles, the pressure on the pavement structure is concentrated, which easily leads to rutting, potholes and other diseases on the pavement. Therefore, the theory of cross-section optimization design requires that the thickness of pavement structure layer should be reasonably increased according to the characteristics of heavy traffic load, and pavement materials with high strength and stability should be selected to improve the overall bearing capacity of pavement. Drainage design is also an important link in the optimization of cross-section alignment. During the driving of heavy-duty vehicles, water splashing is serious. If the drainage is not smooth, it will reduce the friction between the road surface and the tires and increase the hidden danger of driving safety. Based on this, the theory of cross-section linear optimization design advocates setting reasonable arch slope and drainage facilities to ensure that the rainwater on the pavement can be drained quickly, keep the pavement dry and improve driving safety.

(4) Optimal design of line sight distance

The line sight distance is very important for the safe driving of heavy traffic. Heavy-duty vehicles are large in size and have relatively many blind spots. Good sight distance can enable drivers to find the road ahead in advance and take timely measures to avoid accidents. The optimal design theory of route sight distance requires that the terrain, obstacles and other factors should be fully considered in the route design process, and the horizontal and vertical combination of the route should be reasonably determined to ensure that the vehicle has enough stopping sight distance, passing sight distance and overtaking sight distance during driving. By setting up signs, marking lines and lighting facilities along the line reasonably, the driver's visual conditions can be further improved and the sight distance effect can be improved.

4. Optimization strategy of highway route design based on safety performance improvement

(1) Optimization strategy of route design based on vehicle dynamics

The principle of vehicle dynamics plays a key guiding role in highway route design under heavy traffic. Because of its large mass and strong inertia, heavy-duty vehicles show unique dynamic characteristics during driving. In the plane design of the route, according to the centrifugal force formula when the vehicle turns, the radius of the horizontal curve should be appropriately increased. At the same time, the length and parameters of the transition curve are reasonably set, so that the vehicle can smoothly transition to the curve driving state and prevent the safety problems caused by the sudden change of centrifugal force.

In the longitudinal section design, the power and braking requirements of heavy-duty vehicles when climbing and downhill are considered. According to the dynamic performance of the vehicle, the longitudinal slope is limited to avoid the difficulty or even flameout of the vehicle due to excessive slope. For downhill sections, facilities such as emergency lanes are set up to provide a safe buffer area for heavy-duty vehicles with brake failure. In addition, according to the height of the vehicle's center of gravity and the driving speed, the radius of the vertical curve is accurately designed to reduce the bumps and vibrations generated when the vehicle is driving on the vertical curve and improve the driving safety.

(2) Optimization strategy of route design considering pavement structural response

The great pressure of heavy vehicles on pavement structure requires that the response of pavement structure should be fully considered in route design. From the perspective of material selection, high-strength and high-toughness pavement materials, such as modified asphalt concrete,

should be given priority to enhance the ability of pavement to resist heavy vehicle loads. Reasonably design the thickness and combination mode of pavement structure layer, simulate the stress and strain distribution of pavement under heavy vehicle load through mechanical calculation, increase the thickness and strength of base and subbase, disperse vehicle load and reduce fatigue damage of pavement.

In the aspect of drainage design, the influence of heavy-duty vehicles on pavement drainage is considered. Optimize the cross slope of the pavement to ensure that rainwater can be discharged from the pavement quickly, and avoid water accumulation on the pavement to reduce the friction between the tire and the pavement. In addition, a perfect underground drainage system is set up to remove the accumulated water in the pavement structure in time to prevent the pavement structure from softening and damage caused by accumulated water, thus ensuring the structural stability and safety of the highway under the long-term action of heavy traffic.

(3) Route design optimization strategy based on traffic flow characteristics

The characteristics of traffic flow can not be ignored in the route design of heavy traffic highway. Understanding the characteristics of heavy-haul traffic, such as flow, flow direction and peak hours, is helpful to rationally plan the route layout. For sections with heavy traffic flow, ways such as widening lanes and setting special lanes can be adopted to improve road capacity and reduce traffic congestion. In the intersection design, according to the characteristics of large turning radius of heavy-duty vehicles, the turning lane should be widened reasonably, and the setting of signal lights should be optimized to ensure that heavy-duty vehicles can pass through the intersection smoothly and avoid traffic chaos and safety accidents caused by turning difficulties.

Considering the mixed traffic of heavy traffic and other traffic flows, reasonable traffic signs and markings are set in route design to guide different types of vehicles to go their own way. Eye-catching lane separation signs are set on the mixed road sections of heavy-duty vehicles and small vehicles to remind small vehicles to avoid heavy-duty vehicles, reduce mutual interference between vehicles and improve overall traffic safety. By comprehensively considering the characteristics of traffic flow, the route design optimization can effectively improve the operating efficiency and safety performance of highway under heavy traffic environment.

5. Conclusions

This study focuses on the optimization design of highway route and the improvement of safety performance under heavy traffic conditions, and has achieved a series of important results. On the basis of analyzing the characteristics of heavy-haul traffic and the basic principles of highway route design, a systematic theoretical system of optimal design is constructed. Plane alignment optimization focuses on increasing the radius of horizontal curve and reasonably setting transition curve, longitudinal alignment optimization focuses on controlling the radius of slope and vertical curve, cross-sectional alignment optimization emphasizes the bearing capacity of pavement and drainage design, and route sight distance optimization is devoted to ensuring sufficient sight distance.

Based on this, this paper puts forward a targeted optimization strategy. Based on vehicle dynamics, the plane and longitudinal section design can meet the driving demand of heavy-duty vehicles; Considering the structural response of pavement, the durability of pavement is improved through material selection and structural design; Combined with the characteristics of traffic flow, optimize the route layout and traffic organization. These strategies are helpful to solve many problems brought by heavy traffic to highway routes and effectively improve the safety performance and service level of highways.

With the continuous development of heavy-haul traffic and the continuous progress of highway construction technology, there are still many research directions worth exploring in the future. For example, how to further combine intelligent transportation technology to realize intelligent cooperation between highway routes and heavy traffic; Under the background of the emergence of new materials and new technologies, how to better apply them to the route design of heavy traffic highways.

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