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Expressway Route and Interchange Design

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Abstract: With the rapid development of the socio-economy and the growing demand for transportation, highways have become an indispensable and important part of the modern transportation network. The design of highway routes and interchanges is a key link in highway construction, which directly affects the efficiency, safety, and traffic smoothness of highways. Based on this, this article analyzes in detail the highway route design and the design of two common interchanges, in order to improve the highway route design and the quality and efficiency of highway construction.

Keywords: Expressway; Route design; Interchange design

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1. Introduction

Expressway route design is the basis of highway construction and requires reasonable planning based on natural conditions such as terrain, geology, and climate, and actual conditions such as traffic flow, traffic type, and vehicle speed. Interchange design is an important part of highway route design. Its main function is to achieve safe and orderly traffic conversion of vehicles in different directions and speeds. Highway routes and interchange design have evolved in the past few decades, but there are still some problems such as poor route planning and interchange design. Therefore, it is important to study these issues and come up with suitable countermeasures.

2. Highway route design

2.1. Avoiding interference with other construction projects and facilities along the line

2.1.1. Understanding the construction projects and facilities along the line

Before designing a highway route, it is necessary to investigate and understand construction projects and facilities along the route in detail. This includes residential areas, commercial areas, industrial areas, and public service facilities along the route. By understanding the location, scale, construction time, and usage of these construction projects and facilities, appropriate measures can be taken during the design stage to avoid interfering with them.

2.1.2. Avoiding important facilities

When designing a highway route, it is necessary to try to avoid crossing sensitive areas along the route, such as cultural relic protection units, scenic spots, drinking water source protection areas, etc. At the same time, important facilities such as bridges, tunnels, stations, etc. should be avoided. If these areas cannot be avoided, proper protective measures need to be taken to reduce the impact of the projects.

2.1.3. Taking the transportation needs of construction projects and facilities along the line into account

When designing highway routes, the traffic needs of construction projects and facilities along the route need to be considered. When designing the route, transportation facilities such as entrances, exits, and interchanges need to be reasonably set up to meet the travel needs of residents and businesses along the route. At the same time, the connection with urban roads and other modes of transportation also needs to be considered.

2.1.4. Environmental protection measures

Environmental protection measures should also be included when designing the highway route. It is necessary to minimize damage to the surroundings of the route, noise pollution, and air pollution. At the same time, measures also need to be taken to ensure environmental safety issues during construction. These can be achieved by optimizing construction technology and selecting energy-saving and environmentally friendly materials.

2.2. Minimizing land occupation and project cost

When designing highway routes, reducing land occupation and project costs are key considerations. **Table 1** shows some methods or measures that can be taken to minimize land occupation and project costs.

Table 1. Measures to reduce land occupation in highway route design

Method	Description
Route design plan optimization	(1) It is important to make the most of the topography and landforms to reduce damage to the natural environment and the amount of filling, excavation, and land occupation.
	(2) Choosing an appropriate line type can reduce land occupation while ensuring driving safety. When selecting line types, attention should be paid to the reasonable combination of flat curves and vertical curves to avoid creating broken back curves.
	(3) The amount of filling, excavation, and land occupation should be minimized.
	(4) When determining intermediate control points, attention should be paid to coordination with the surrounding environment to avoid excessive control points, thereby reducing land occupation.
Make rational use of land resources	(1) Land use efficiency can be maximized by fully utilizing the land, and reducing land occupation.
	(2) Selecting an appropriate longitudinal slope can reduce the amount of filling and excavation, thereby reducing land occupation. However, the coordination with the surrounding environment should also be considered when designing longitudinal slopes [1].
Reduce project cost	(1) Through rational utilization of land resources, land utilization efficiency can be improved, thus reducing land occupation and overall costs.
	(2) Operation and maintenance costs should be considered when designing highways. By selecting appropriate building materials and taking corresponding measures, operation and maintenance costs can be reduced, thereby reducing project costs.

2.3. Coordinating and unifying routes and large structures

2.3.1. Understanding the location and size of large structures

Before designing a highway route, it is necessary to conduct a detailed investigation and understanding of the large structures along the route like bridges, tunnels, and interchanges. By understanding the location, scale, construction time, and usage of these structures, corresponding measures can be taken during design to achieve coordination and unification of routes and structures [2].

2.3.2. Determining the line type and elevation of the route

The alignment and elevation of the route are key factors in coordinating the route and large structures. Design standards and requirements for large structures need to be considered when determining the alignment and elevation of the route. For example, if the route is near a bridge, it is necessary to align the route with the bridge; the route elevation should not be higher than the bridge deck elevation, thereby avoiding adverse effects on the bridge.

2.3.3. Construction methods and techniques surrounding structures

The construction methods and techniques of large structures are also important factors in achieving the coordination and unification of routes and structures. When designing the route, it is necessary to consider the construction method and technology of the structure when determining the line shape and elevation of the route. For example, if the route is near a tunnel, it is necessary to align the route with the entrance and exit of the tunnel, so as to ensure the safe use of the tunnel.

2.3.4. Ensuring the safety and the smoothness of traffic flow

The safety and the smoothness of traffic flow should be considered when designing highway routes. While achieving coordination between routes and large structures, corresponding measures need to be taken to ensure smooth traffic flow. For example, there should be traffic signs and markings for routes that are near a bridge to ensure that vehicles can cross the bridge safely; if the route is near a tunnel, reasonable traffic control measures need to be taken to ensure that vehicles can enter and exit the tunnel safely [3].

2.4. Strengthening environmental protection and highlighting the beauty of natural landscapes

2.4.1. Respecting the natural environment

When designing highway routes, it is necessary to respect the natural environment and protect and utilize existing natural landscapes as much as possible. It is crucial to minimize the damage to the natural environment and retain the original topography, landforms, and vegetation of the area. At the same time, the route alignment and elevation should be reasonably selected based on the characteristics of the natural environment characteristics of different areas to avoid excessive excavation, filling, and destruction of vegetation [4,5].

2.4.2. Considering ecologically sensitive areas

When designing highway routes, ecologically sensitive areas such as nature reserves, water source reserves, wetlands, etc. should be considered. These areas should be avoided to reduce damage to the ecological environment. If it is necessary to travel through these areas, corresponding protection measures should be taken, such as setting up ecological corridors and restoring vegetation, to maintain the stability of the ecological environment and biodiversity.

2.4.3. Green design

Green design is an important means to highlight the beauty of natural landscapes. Green design should be applied in designing highway routes. To achieve green design, a variety of plant configuration methods can be adopted to restore and protect the vegetation along the highway. The type of plants used should be selected based on the local climate and soil conditions to ensure the survival and ecological benefits of vegetation.

2.4.4. Strengthening environmental management and monitoring

When designing highway routes, environmental protection management and monitoring should be strengthened. A complete environmental protection management system and monitoring mechanism should be established to supervise and manage environmental protection work during the construction process. At the same time, the environmental impact of the construction process should be monitored and analyzed, and corresponding measures should be taken to reduce the impact on the environment.

3. Common highway interchange designs

3.1. Trumpet-shaped interchange

3.1.1. Characteristics of trumpet-shaped interchange

The design of the trumpet-shaped interchange is a design method that emphasizes efficient guidance and safety of road traffic flow [6]. The main purpose of this design is to realize smooth traffic flow and ensure traffic safety by creating a three-dimensional intersection of traffic flow in different directions. Its characteristics mainly include the following three points.

(1) Singular entrance and exit

A trumpet-shaped interchange typically features a singular entrance and exit, usually in the form of a direct connection. This design allows vehicles to enter or leave the interchange quickly, aiding rapid vehicle identification and navigation. Additionally, this design minimizes traffic congestion often caused by numerous forked intersections.

(2) Minimal land occupation

Since the trumpet-shaped interchange resembles an intersection, it efficiently manages traffic flows in various directions within confined land resources. Therefore, it occupies a smaller area compared to other forms of interchanges.

(3) Facilitating ramp toll station installation

Ramp toll stations can be set up easily at trumpet-shaped interchanges. Toll stations can be strategically positioned along the ramps, allowing for efficient vehicle toll management [7].

3.1.2. Steps of designing a trumpet-shaped interchange

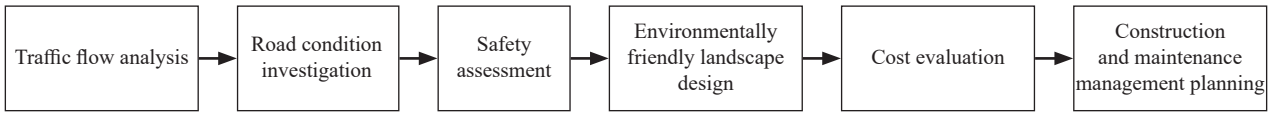

Figure 1. Steps of designing trumpet-shaped interchange

The steps of designing a trumpet-shaped interchange are shown in **Figure 1**. This includes examining traffic volume and speed in each direction, forming the basis for determining the scale and quantity of lanes within the interchange. Following the traffic analysis, a thorough assessment of road conditions is conducted,

encompassing factors such as road grades, restrictions, layout, and other relevant aspects. These factors contribute to determining the placement, shapes, and dimensions of the entrance and exit points within the trumpet-shaped interchange [8]. Subsequently, a traffic safety assessment must be conducted to determine the safety measures for the trumpet-shaped interchange, such as warning signs, markings, anti-collision facilities, etc. Moreover, environmental protection and landscape effects should also be considered in the design process. In addition, it is necessary to conduct a detailed analysis of construction costs and maintenance costs, and cost-effective materials and equipment should be utilized to reduce overall costs. Furthermore, social benefits like improving traffic conditions and increasing travel efficiency should also be taken into account. Lastly, a detailed construction and maintenance management plan needs to be formulated, including construction plans, safety measures, quality control, etc., to ensure the smooth progress of the project and the convenience of subsequent maintenance.

3.1.3. Design control indicators

The design of the trumpet-shaped interchange needs to meet a series of control indicators, including plane, longitudinal section, cross section, connection, and other aspects. These indicators serve to ensure the rationality, effectiveness, and safety of interchange design. For example, plane indicators include the length, the width, and the radius of curvature of ramps; vertical section indicators include maximum longitudinal slope, minimum vertical curve radius, etc.; cross-sectional indicators include lane width, road elevation, road shoulder width, etc.; and connection indicators include the length of gradient sections, ultra-high gradient rate, etc.

3.2. Y-shaped interchange design

3.2.1. The characteristics of a Y-shaped interchange

A Y-shaped design is a common type of highway interchange design. It is usually employed to solve the intersection problem of highways and other roads or transportation hubs. The Y-shaped interchange is characterized by a “Y” shape between the main line and the branch line, providing a space for vehicles to divert and merge. There are five main features of this design, which are described in **Table 2**.

Table 2. Features of a Y-shaped interchange

Features	Description
Directional or semi-directional operation	A Y-shaped interchange facilitates high-speed directional or semi-directional maneuverability for turning vehicles, enabling smooth completion of steering operations and enhancing overall traffic flow.
No intersection and conflict points	Through reasonable lane layout and traffic organization, the vehicles in different directions can be separated effectively. Besides, interweaving and conflict points are eliminated, hence improving road safety.
Driving safety	The use of grade-level intersections avoids potential traffic safety hazards caused by level intersections and improves driving safety.
Clear navigation and a short path	Its shape and landmarks enable drivers to navigate easily, reducing driving distances and ultimately enhancing overall traffic efficiency.
Small footprint	Through reasonable layout and optimized design, the scale of land use is reduced and land resources can be effectively utilized [9].

3.2.2. Design steps of Y-shaped interchange

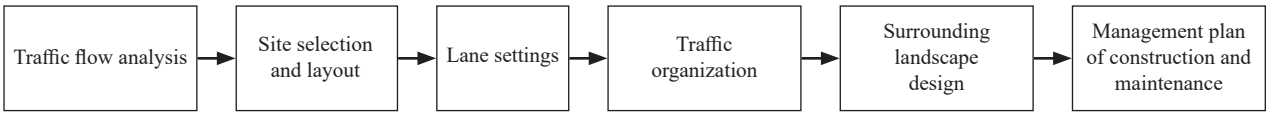

Figure 2. Y-shaped interchange design steps

The steps of designing a trumpet-shaped interchange are shown in **Figure 2**. The first step of designing a Y-shaped interchange is to investigate the traffic flow at the intersection to understand the traffic flow and speed in each direction to provide a basis for lane setting and traffic organization [10]. Then, a suitable location is selected for the construction of the Y-shaped interchange based on the condition of the terrain and road network planning. At the same time, it is necessary to consider the surrounding environment and landscape factors in the process of designing the interchange. Based on the traffic flow analysis results, the appropriate number of lanes and variable speed lanes, and the width and length of the lanes are determined. Then, based on the traffic flow and lane setting, a reasonable traffic organization design is carried out, including vehicle steering, lane priority, traffic light timing, etc. Landscape design is also carried out for the interchanges, encompassing greening, lighting, and buildings to create a visually appealing landscape effect. Factors such as ecological and environmental protection need to be considered. Lastly, detailed construction plans, safety measures, quality control, etc. are formulated to ensure the smooth progress of the project and the convenience of subsequent maintenance and management.

4. Conclusion

With the advancement of science and technology, environmental protection and sustainable development will be increasingly emphasized in future highway route and interchange designs. In route design, the influence of natural conditions such as terrain, geology, climate, etc. will be further considered, and more scientific and reasonable design methods and means will be adopted to improve the safety and comfort of the route. In the design of interchanges, more emphasis will be placed on improving traffic conversion efficiency and traffic safety, while strengthening environmental protection measures to reduce damage to the natural environment. Furthermore, due to the rapid advancement and expanded implementation of intelligent transportation systems, there will be increased utilization of information and smart technologies to enhance highway operational efficiency and service standards. Consequently, future highway route and interchange designs will progress towards a more environmentally conscious, efficient, and intelligent direction.

Disclosure statement

The author declares no conflict of interest.

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