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Exploration of paths related to green highway planning and design based on the whole life cycle

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Abstract. In recent years, highways, as an important infrastructure in the field of transportation, have played a significant role in economic development, people's travel and other aspects. However, with the expansion of scale and the increase of operation mileage, the conflict between highway and environment is also becoming increasingly serious. In order to implement China's ecological civilization construction concept, the whole life cycle of the green highway has gradually turned into an industry-oriented, including energy-saving and environmentally friendly projects such as the Tarim Desert Highway. This paper will start from the current situation of green highways. Based on the green concept, it will cover three phases: preliminary planning, construction and implementation, as well as operation and maintenance. Through aspects like the case route design, material selection, and construction technology, it aims to explore the high - quality development path for the whole - life cycle of green highways and enhance planning and design. From the dimensions of material, management, and infrastructure, it synergistically boosts highway transformation. Meanwhile, it provides reference for its high-quality development.

Keywords: Green highway; Whole life cycle; Ecological conservation; Resource recycling; Planning and design.

1. Introduction

The concept of a civilization that adheres to, respects and protects nature is highly valued in China. As one of the important infrastructures, highways play a great role in stimulating regional economic growth, promoting the synergistic development of various industries and facilitating people's travel. However, as its scale continues to expand and its operational mileage increases, the contradiction with the environment has become increasingly acute. Currently, the green highway design concept—incorporating ecological protection, low-carbon operation and efficient transportation—is gradually evolving into an emerging industry-oriented concept. By the end of 2023, the total mileage of highways in China will be 5.437 million kilometers, with 184,000 kilometers of highways [1]. These include many energy-saving and environmentally friendly highway projects, such as the Tarim Desert Highway, completed in 1995, which applies a scientific desert sand protection system and realizes a zero-carbon power supply for 519 kilometers through the construction of 86 photovoltaic power stations [2]; Another example is the Nanzhong Expressway, an important part of the national highway network G2518 and Guangdong Expressway S78. The project integrates the concept of green development into the entire life cycle and has developed ten innovative technologies in four categories, such as industrialized intelligent construction of highway bridge groups and comprehensive utilization of highway resources, initially establishing a typical urban agglomeration green bridge group highway technology system [3].

In the S309 Tiangao Line reconstruction project from Shouguang Fork River to the Weifang-Dongying boundary, the green highway concept was implemented during the design stage. Measures include the integrated use of transport corridor alignment resources, adoption of low embankment and shallow trench schemes based on local conditions, promotion of prefabricated construction technologies, and implementation of ecological and air pollution prevention and control measures [4].

From the perspective of industry development, green highway is a novel highway development model that shifts from traditional low carbon to innovation and is committed to exploring and researching

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new energy sources, new materials, new equipment and new processes. The core of its development is to take the whole life cycle as a framework, reduce resource consumption, protect and improve the ecological environment, and realize the green benefits of the output process [5]. For this reason, this paper combines the design principles, ecological concepts, transportation efficiency, optimization paths and technological challenges of green highways in domestic and international literature, and based on the green concept, discusses how to practice the high-quality development of green highways in the whole life cycle of highways to improve their planning and design.

2. Planning for green highway construction

2.1. Planning Objectives

With the core of "ecological friendliness in the whole life cycle, efficient recycling of resources, and optimal transportation efficiency", it realizes the synergistic development of highway construction and ecological protection, which includes: reducing the ecological impact by more than 30%, utilizing waste materials by more than 80%, reducing the cost of the whole life cycle by 15%, and improving the road network efficiency by 20% [6].

2.2. Stages

2.2.1. Pre-planning phase (1-2 years)

First, carry out the ecologically sensitive area investigation. Combine remote sensing technology with field survey to clarify the avoidance range of nature reserves, wetlands, etc., adhering to the principal system of "ecological priority, systematic synergy" [5]. Secondly, optimize the road network. Based on the concept of "grid-type road network" [6], improve the connectivity of nodes and reduce the detour distance. For example, in small and medium-sized cities, the road network density can reach more than 7km/km² by adding feeder roads and opening broken roads.

2.2.2. Construction implementation phase (3-5 years)

During the construction and implementation phase, the materials used in green highways need to be able to be recycled, and recycled asphalt and recycled aggregates from construction waste are currently excellent choices [7,8], as shown in Fig. 1 and Fig. 2 [10]. Secondly, a regional materials recycling network needs to be established to integrate recycling resources, facilities and channels to reduce resource waste and optimize deployment. The use of ETC, intelligent monitoring and other technologies in appropriate road sections can improve the efficiency of toll plazas, reduce vehicle idling emissions, and achieve the goal of "green" [9].

Fig 1. Simply crushed recycled coarse aggregate [10]

Fig 2. Reinforced recycled coarse aggregate [10]

2.2.3. Operation and maintenance phase (long-term)

On the one hand, efforts should be made to enhance preventive maintenance by applying micro-surfacing and thin-layer overlay technologies to extend the service life of pavements [11]. Emphasis should be placed on resource conservation and sustainability throughout the operation of highways, and their service life should be reasonably prolonged through preventive measures, thereby practicing the concept of an efficient whole-life cycle.

On the other hand, environmental monitoring is strengthened, and a real-time monitoring system for noise and dust is established to take timely measures to reduce dust and noise [12]. Through all-weather dynamic recording of noise, dust and other data, to grasp the degree of impact of highway operation on the surrounding environment and change trends. Once the data exceeds the preset index, active management measures such as dust and noise reduction can be triggered, forming a closed loop of "monitoring - management".

3. Green Highway Design Program

3.1. Route design

Following the principle of "giving priority to ecology and adapting to local conditions", route planning is carried out in full consideration of the topography and distribution of ecologically sensitive areas. In the selection of routes, it should meet the requirements of intensive use of channel resources and flexible selection of routes, and consider the common channels of highways, high speeds, railroads, to reduce waste and division of land resources. For ecologically sensitive areas such as wildlife protection zones and water source protection zones, avoid them through remote sensing surveys and field research. Avoid basic farmland and adopt shallow road graben and low embankment design. More than 5km from the core area of the nature reserve, more than 100m buffer zone is set around the wetland, and the sensitive section of the river is crossed by bridge [5]. At the same time, it is necessary to pay attention to the connection with the neighboring road network, enhance the connectivity of the road network, reduce the vehicle detour distance, and improve transportation efficiency. In terms of terrain adaptability, wiring along river valleys and mountain trends reduces earth and rock excavation. The mountainous sections follow the "bridge-to-tunnel ratio priority", avoiding large-scale cutting of mountains and filling of valleys. Adopt the technology of "zero-excavation tunneling" to reduce the destruction of mountain vegetation [5].

3.2. Material selection

The application of environmentally friendly materials in highway construction has been actively promoted to achieve the dual goals of resource conservation and environmental protection. For asphalt, recycled materials and bio-asphalt are used. Recycled aggregates from construction waste in

recycled materials can be used for backfilling of road base, and graded gravel processed with tunnel rejects is used for base layer [8]; bio-asphalt replaces petroleum-based components with plant-based raw materials, which can reduce carbon emissions by more than 30% [7].

Road construction prioritizes the use of warm mix asphalt mixtures to replace ordinary hot mix, reducing soot emissions and energy consumption. At the same time, the application of asphalt cold and hot regeneration, semi-rigid grass-roots cold regeneration and other technologies are combined with the actual situation to save materials and control costs. The backfill of road base can be processed by crushing and screening of construction waste. For example, in Qingyang County municipal road project, the replacement rate of recycled aggregate reaches 60%, reducing mountain quarrying and protecting mountain ecology. Anhui Yuewu high-speed tunnel waste is processed into slate retaining walls, saving 40% of the cost of stone [5], as shown in Fig. 3 [14].

Fig 3. On-site sampling of recycled construction waste [14]

3.3. Construction process

First, the use of low-carbon construction: asphalt mixing building “oil to gas”, reducing waste emissions by 40% [9]. The use of warm mix asphalt technology, mixing temperature control at 160-180 ℃ [7]. The second is to take certain environmental protection measures: set up a fence in the construction site boundary to reduce dust, noise-sensitive areas using low-noise equipment, night construction noise does not exceed 55dB [13].

3.4. Ecological protection

Adopt guest soil spraying technology to plant native drought-tolerant plants [5]. Mix seeds, fertilizers, soil conditioners, and other materials and spray them onto slope surfaces to form a substrate layer with certain strength and water retention capacity. Planting local drought-tolerant plants—with high adaptability—helps maintain ecological balance.

The ecological side ditch adopts planted grass bricks with permeable bedding layer, and the rainwater is purified and reused [8]. The planted grass bricks have good water permeability, which facilitates the initial purification of rainwater. The permeable mat layer enhances the infiltration of rainwater, which can quickly infiltrate and replenish groundwater. The purified rainwater can be reused for highway greening irrigation and pavement sprinkling. The circulation of rainwater enhances the utilization of water resources and reduces the pressure on the ecology.

4. Reflections on the development trend of green planning for roads

Looking forward, there is still a need to improve policy norms and establish a more scientific evaluation system for green highways; and to strengthen cross-field cooperation, integrate transportation, ecology and other resources, and form a synergy for promotion. The innovation and recycling of high-performance green materials, the application of intelligent regional management

system, and the deepening of the concept of green highways will be an important direction for the continuous exploration and breakthrough of green highway construction.

Through the concerted efforts of all industries, the green highway will play a more important role in promoting the sustainable development of the transportation industry and contributing to the construction of ecological civilization, creating a better travel environment and ecological home for people.

5. Conclusion

As a key path to the development of the transportation industry, green highways are of great significance in promoting the coordination of transportation and the ecological environment. Through the synergistic promotion of the three phases of preliminary planning, construction and implementation, and operation and maintenance, and with the goal of "ecological friendliness in the whole life cycle, efficient recycling of resources, and optimal transportation efficiency", the contradiction between highway construction and the ecological environment has been effectively mitigated.

(1) In the preliminary planning stage, ecological environment factors were fully considered, and ecologically sensitive areas were reasonably avoided laying the foundation for green highway construction. During the construction and implementation process, environmentally friendly materials and low-carbon construction techniques are used to reduce energy consumption and pollutant emissions. In the operation and maintenance stage, the maintenance and management of highway facilities are strengthened to improve resource utilization efficiency and ensure the safe and stable operation of the highway.

(2) At the design level, the greening of the slope face facilitates ecological restoration, and the drainage system realizes the purification cycle of rainwater. The optimized design guarantees the safety and stability of the highway. It also promotes the restoration of the ecosystem and the recycling of water resources.

The construction of green highways has achieved a win-win situation for both transportation development and ecological protection. In the future, with the continuous progress of technology and the continuous updating of concepts, the green highway will play an important role in more fields and inject new vitality into the sustainable development of the transportation industry.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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