

Measures and Suggestions for Ecological Restoration of Highway Slopes in the Context of Green Highway in China

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Abstract. To practice green development in highway construction and improve the theory slope ecological restoration, this paper analyzes the connotation characteristics and idea of green highway, and puts forward the needs and management suggestions of green highway idea for slope ecological restoration. The results show that: (1) the ecological restoration of highway slope should adapt to the needs of green highway development in the new period from five aspects: optimizing design, intensive using of resources, adopting different repair techniques, considering the life cycle costs and building beautiful highways. (2) The high-quality development of ecological restoration of highway slopes can promote from four types of initiatives: encouragement, compulsiveness, recommendation and guidance. The research results provide guidance and strategy for develops slope ecological restoration, which is conducive to promoting the transportation industry to practice green development and ecological civilization strategy.

Keywords. Green transportation, green highway, side slope, ecological restoration, management suggestion

1. Introduction

The strategy of ecological civilization and green development have become the basic principles to promote the healthy development of various industries and fields. Promoting to make ecological civilization and practicing the green idea have become the inherent needs of the high-quality development of the transportation industry. China attaches great importance to the green development of transport. One of the important tasks of the “Outline of Building a Country with Strong Transportation” is to strengthen in protect and repair of transportation ecological environment. Transportation ecological restoration project is proposed in the “Outline of the National Integrated Stereoscopic Traffic Network Planning”. Green highway embody the idea of ecological civilization. Slope is an important part of highway, and ecological restoration of slope can solve environmental contradiction caused by slope engineering construction. Under the background of ecological civilization construction and green highway construction,

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slope ecological restoration is facing new requirements. It is necessary to study the countermeasures and suggestions of slope ecological restoration from the perspective of green highway.

Developed countries such as the USA, Germany and France started to apply the spraying technology in the slope since the 1960s. In the 1980s, Japan introduced continuous fiber reinforced geotechnical method from France [1]. After decades of development, a whole set of technical have been formed in ecological restoration of highway slopes. In general, the research on slope ecological restoration technology in Europe and the United States has focuses on preventing the slope from rain erosion. Protection of topsoil from surface erosion and soil degradation by covering slope effectively and timely. Reinforcing the soil and improving anti-skid through plant roots holding the soil in place and reducing soil pore water pressure. Stabilization and strengthening of slopes by matching plants with stones, cement, steel, plastics and timber. Lack of experience in ecological restoration of slopes at the early stage of highway construction in China. Most of the slope protection adopted was hard protection such as slurry slabs and concrete walls, which had a certain impact on the natural environment and ecological balance [2]. From the late 1990s to the beginning of the 21st century, Slope protection of China began to draw on the vegetation restoration techniques of foreign countries such as Europe, America and Japan. The focus of slope protection is changing from engineering to the Coordination of ecology and engineering [3].

There are many technologies for ecological slope restoration of highways in China, but most studies focus on the selection and arrangement of plants, the ratio and characteristics of ecological substrate, etc. Lack of attention on systematicness, integrity and sustainability of slope ecological restoration. Under the requirements of the idea of green highway, the relevant theories and methods can no longer meet the needs of ecological restoration of highway slope in the new era, which needs to study in depth. This paper analyzes the development direction of slope ecological restoration from the perspective of green highway, and puts forward suggestions for slope ecological restoration management. This paper can improve the theory of slope ecological restoration and promote the harmonious coexistence of transportation and nature.

2. Idea and Requirements of Green Highway

2.1. Idea and Connotation of Green Highway

Green highway follows to meet the reasonable traffic demand with the least investment and the least environmental cost. It is a strategic measure for the to strengthen to build ecological civilization in the transportation industry and the key content of building a strong transportation country.

In philosophical, the core idea of green highway is to realize the organic unity of economic, social and environmental benefits of highway construction and harmonious coexistence with nature. The requirements which is energy conservation, high efficiency, environmental protection and health should be implemented in all highway construction, design, construction [4].

According to the requirements of high-quality development, green highway construction adopts the theory method to coordinate all planning, design, construction and management of highway, and between quality, save resources, energy consumption, pollution emission, ecological impact and efficiency. To achieve the comprehensive

objectives of high durability, high applicability, landscape coordination, environment friendly, resource conservation, operation security and service improvement, green highway construction optimizes the project scheme according to local conditions, designs and implements carefully, improve project quality, improve service function, improve operation efficiency, minimize resource, energy consumption and environmental impact [5].

2.2. Characteristics of Green Highways

The characteristics of green highway can be summarized as “High potency, High efficiency and High benefit”, “Low consumption, Low emission, Low pollution” and “All life, All factor, All dimensions” (Figure 1).

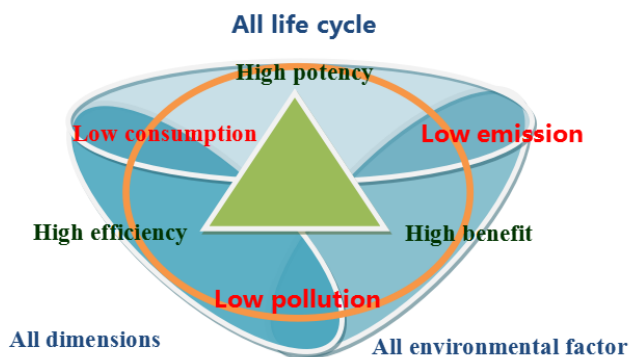


Figure 1. Characteristics of Green highways.

(1) High potency means maximizing overall efficiency and service capacity through integrated use of green technologies and measures over the life cycle. High efficiency requires the most effective use of natural, social and economic resources to achieve the optimal allocation of resources. High benefit requires to obtain the maximum benefits of sustainable development at the minimum cost of ecological resources.

(2) Low consumption means that it has the advantages of energy saving and low energy consumption. From the perspective of material use, the green highway adopts renewable or degradable materials. Low emission requires less pollutants even zero emission during construction. Low pollution requires the design and construction should not be at the cost of destroying nature, surface structure and biodiversity.

(3) All life requires the green idea and technology run through the life cycle of planning, design, construction, operation and maintenance. All factor requires the green requirements of energy saving, high efficiency, environmental protection and health should be implemented in all highway construction design and construction. All dimensions control requires that green highway not only pay attention to construct main highway engineering, but also create necessary conditions for green transportation and safe operation.

2.3. Basic Requirements for idea of Green Highway

Green highway is fully absorbing the past highway construction idea, integrating the requirements of ecological civilization and green development, and improving the new idea of highway construction and development. The first is to set up the idea of “No damage is the maximum protection”, and achieve maximum protection, minimum damage and the strongest recovery. The second is to set up the idea of “Intensive and economical use of resources” to improve the efficiency of resource and energy utilization, and reduce total energy consumption and waste production. The third is the idea of “Flexible design”, flexibly use technical signs to maximize the coordination between the highway and the natural and cultural environment along the line while ensuring safety and role. The fourth is the idea of “People-oriented” and design should be carried out according to the needs of drivers and passengers. The fifth idea is the “Creation design”, giving highway personality. The sixth idea is the “Minimum life cycle cost”, and integrate the needs of highway operation, maintenance and use into the comprehensive consideration of engineering design and construction. The seventh is the idea of “Inheriting history and culture”, It should be encouraged to construct highway as a display platform of natural scenery, history and culture and tourism resources. The last one is the idea of “Appropriate landscape greening”. To improve highway greening landscape should adapt to the surrounding environment. Excessive greening or artificial landscape and landscape improvement incompatible with the surrounding environment are not advocated [6].

It can see the idea of green highway has three new requirements for slope ecological restoration. The first is the idea of holistic and systematic sustainable development is added. The second is to comprehensively consider the multi-objective of economy, energy conservation, environmental protection and landscape and so on. The third is paying attention to reducing the life cycle cost and promoting to recycle of materials.

3. Suggestions on Slope Ecological Restoration Management for Green Highway

Ecological restoration of slope is an important tool of the idea of green highway. The new requirements of green highway idea should carry out from five aspects: optimized overall design, saving and intensive resources, adapting measures to local conditions, coordinating life cycle and creating beautiful highways.

3.1. Optimization design

The idea of “no damage is the maximum protection” and “flexible design” required the over design optimization of highway slope ecological restoration should carry out from the aspects of optimization of route selection design, optimization of engineering scheme, flexible technical signs, and application of Building Information Modeling (BIM) technology.

(1) Best highway route should be selected to reduce ecological damage of highway. Selection of highway alignment is based on the principle of the shortest crossing and the least ecological impact to reduce the high and steep slope and the high fill deep excavation [7]. For example, twin-spiral tunnel optimization line index was optimized in Yaxi highway of Sichuan to reduce the number of slopes from the source (Figure 2).

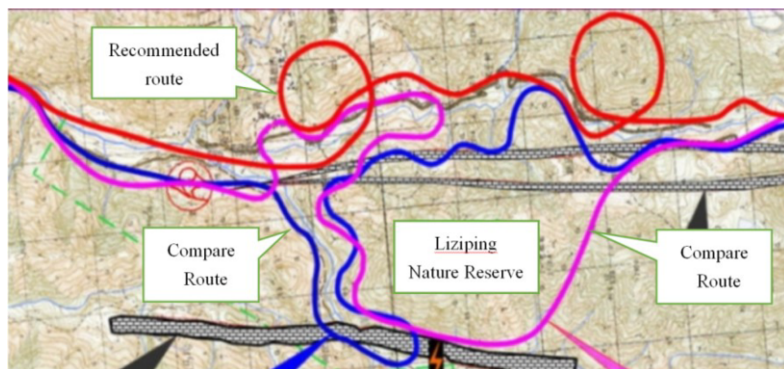


Figure 2. Twin-spiral tunnel optimization line index was optimized in Yaxi highway of Sichuan.

(2) Engineering scheme of less disturbance should be selected. Pay attention to the selection of high cut and deep cut subgrade scheme. For deep excavation sections, when the excavation height is greater than 20 m or the stability is poor, it is advisable to consider the option of a tunnel instead of a roadbed or a shed hole. For high-fill sections, topography can be protected by using half-roads and half-bridges, bridges instead of roads and low subgrade. For the tunnel portal, the principle of “early entry and late exit” should be advocated, and the open-cut portal are preferred to reduce earthwork excavation. For example, half-roads and half-bridges was adopted in the Shenlongjia highway of Hubei (Figure 3), and bridges instead of roads was used in Yaxi highway of Sichuan (Figure 4).



Figure 3. Half-roads and half-bridges adopted in the Shenlongjia highway of Hubei.



Figure 4. Bridges instead of roads used in Yaxi highway of Sichuan.

(3) Flexible use of technical signs to control the number of slopes. In the construction environment such as high altitude, frequent geological disasters and heavy hills, it is recommended to select technical standards in sections and flexibly use technical signs to control the scale of slopes. For example, Chuanjiu highway of Sichuan province adopts different technical signs according to road conditions, flexibly determines the slope rate, changes the line to curve slope to reduce the slope scale (Figure 5).



Figure 5. Determination of slope rate by flexible operation technical index in Chuanjiu highway of Sichuan province.

(4) BIM technology should be used to optimize slope scheme. BIM technology can simulate slope engineering to optimize the slope scheme from quantity, slope and ecology [8].

3.2. Concentrated Resources Use

The new requirements of green highway idea of “intensive and economical use of resources” should be implemented from five aspects: tunnel spoil utilization, industrial solid waste utilization, Utilization of waste resources, topsoil collection and utilization, and Utilization of Plant Transplantation.

(1) Tunnel spoil utilization. Tunnel spoil is used as slope stone and gravel material for slope protection in highway construction.

(2) Industrial solid waste utilization. Industrial solid waste such as steel slag, silty soil, waste concrete, coal gangue, slag, waste tires was used in slope structural materials [9].

(3) Utilization of waste resources. The waste template, bamboo, straw, coconut shell and other resources along the project are used as slope protection materials to realize the protection of slope soil. For example, the ecological restoration technology of fencing formed by using waste templates for slope protection in Xiaomo highway, and good ecological effects have been achieved (Figure 6).

(4) Collection and utilization of topsoil. Topsoil is collected before construction for slope repair. For example, topsoil can be sieved and used for sprinkling substrate or slurry preparation.

(5) Utilization of Plant Transplantation. For the plants that must be cleared within the scope of highway land requisition, the utilization scheme should be formulated on the basis of detailed investigation for slope greening.



Figure 6. Utilization of waste materials used in slope protection of Xiaomo highway.

3.3. Take Different Repair Techniques in Line with Different Slopes

The idea of “creation design” and “moderate landscape greening” of green highway requires to select economic and applicable technologies according to local conditions, such as climatic conditions, slope gradient, slope direction and soil texture and other conditions. It is necessary to carry out artificial induction from the flexible selection of slope restoration schemes, near-natural terrain treatment and flexible selection of slope plants to accelerate ecological restoration.

(1) Flexible selection of ecological restoration technology. Flexible selection of slope ecological restoration technology is based on slope soil type and slope gradient (Table 1).

(2) Near-natural terrain remediation. Referring to the adjacent undisturbed topographic features, the slopes are gently sloped to ensure stability and reduce the folded landscape at the top of the slope to achieve a natural transition.

(3) Flexible selection of slope plants. The pioneer species, constructive species and associated species should be identified according to the environmental conditions [10]. For example, in the southern region with good water conditions and abundant rainfall, reasonable selection of trees, shrubs and grass to create slope protection vegetation. In arid or semi-arid areas of the North, irrigation and grass measures are recommended.

(4) Moderate greening of slope. Vegetation coverage is not the only standard for the success of ecological slopes, and slope greening integrated with the surrounding environment should be constructed. For example, it is unnecessary to green by grid for Stable bare rock slope.

Table 1. Ecological restoration technology of highway slope.

Type of technology	Sphere of application
Hydro-seeding	It is suitable for soil or soil-rock slope, and for broken rock slope, and no strict requirements on slope ratio
Sprinkler greening	It is suitable for soil-free slopes with less soil composition, high soil hardness or rock, rock pile, granite weathered sand, bulk rock, polar acid soil rock, and the slope ratio is not greater than 1:0.3.
Greening with growth bag	It is suitable for stone slopes reinforced (such as square concrete ribs) and lower stone slopes. It can apply to all kinds of steep slope with bad rock condition after relevant reinforcement measures.
Drilling planting greening	It is suitable for slopes with stone, poor soil, earth and rock, where overall slope stability is required
Greening of frame beam protection engineering	It is suitable for rock slope with severe weathering and high soil slope with stable slope surface, with slope height less than 10 m per grade.
Cover net vine climbing greening	It is suitable for the greening of rocky slopes with a maximum slope gradient of 90 degrees on excavated sections with good stability and without the need for any other protective works.
Stepped wall greening	It is suitable for hard-to-recover but landscaped excavated sections.
Plant fiber blanket slope protection greening	It is suitable for various types of soil slopes. According to the requirements of slope protection, two greening methods are selected: first cover plant fiber blanket and then sowing and then cover plant fiber.
Turfing	It is suitable for soil slopes requiring protection or greened quickly
Greening soil in geocell	It is suitable for various harsh soil conditions of mudstone, limestone, sandstone and other rock slope. It has strict requirements for slope and slope flatness, and the slope should not exceed 1: 0.75. When the slope is greater than 1:1, it should be used cautiously.
Three-dimensional netting for soil consolidation greening	It is suitable for the slope ratio should not be greater than 1:1 for excavation slope with poor soil and fill slope with mixed soil and stone.
Planting bags for greening	It is suitable for soil embankment slopes with slow slope and relatively good soil conditions. Soil-rock mixed embankment slopes can be used after treatment, and can also be used for soil cutting slopes. The commonly used slope ratio is 1:1.5-1:2.0. When the slope ratio exceeds 1:1.25, other methods should be combined.
Shrub planting shrub technology	It is suitable for rock or soil slopes with thickness, slope less than 50° and high soil quality
Comprehensive ecological protection technology of grid grass planting in hexagonal bucket	It is suitable for sandy soil embankment slope with serious desertification and poor stability

3.4. Consider Life Cycle Costs

The idea of “minimum life cycle cost” of green highway requires to integrate life-cycle costs of slope restoration in near-natural ecological restoration, durability and safety monitoring.

(1) Ecological restoration of near-natural slope. Slope ecological restoration scheme should not merely pay attention to the first construction cost of the project but maintenance costs. Therefore, ecological restoration of near-natural slope should be selected [11]. It can simulate a plant community close to its natural state, restoring the driving force for self-renewal of highway plants and reducing the cost of highway maintenance and management. It can simulate the plant community close to the natural state, restore the driving force of self-renewal succession of highway plants to reduce the cost of highway maintenance and management in the late stage.

(2) Sustainability of slopes. The ecological restoration plan should be determined by the slope considering the geological conditions, climatic characteristics, shape of the

slope and soil characteristics to avoid “cosmetic works” that wither quickly due to lack of maintenance.

(3) Slope safety monitoring. Slope on-line monitoring should be installed in slopes with complex engineering conditions [12]. High-precision and high-reliability monitoring sensors are used to monitor the bearing capacity, status and durability of the supporting structure to meet the requirements of safe operation.

3.5. Creating Beautiful Highways

The idea of “inheriting history and culture” and “people-oriented” of green highway, which required the ecological landscape should be created through the ecological restoration of the slopes, to realize the purpose of constructing tourist highway.

(1) Creating beautiful highway landscape. From the perspective of safety and aesthetics, plant varieties and planting forms are selected to form the rhythm changes of colors to create beautiful highways [13].

(2) Beautifying key nodes of highway. Based on the principle of integrating with nature and highlighting characteristics, the slopes of key nodes such as highway service area and tunnel entrance should be beautified. For example, the slope of the service area of Shanzhan Expressway is built as a roof shape, integrated with the building and surrounding environment of the service area.

(3) Culture propaganda by slope. Stone carving, painting and relief are used on stone slopes or keeping walls for cultural promotion.

4. Suggestions on Slope Ecological Restoration Management from the Perspective of Green Highway

4.1. Encouraging Measures and Suggestions

(1) All slopes that have been constructed should be repaired. Based on the highway ecological restoration during 13th Five-Year and engineering practice in recent years, the slope ecological restoration should be carried out comprehensively for the built highways crossing the ecologically sensitive and fragile areas.

(2) Ecological restoration funds should be disbursed for new and reconstruction projects. The ecological restoration funds should be separately disbursed in the construction and installation costs to ensure the investment demand of ecological restoration in the new and reconstruction project [14].

4.2. Compulsive Measures and Suggestions

(1) Highway projects should carry out the special design of ecological restoration. Aiming at the ecological restoration of highway slope, the special design is carried out.

(2) The acceptance time of slope ecological restoration should be extended. Ecological restoration of highway slope needs a certain period of time, it is suggested to appropriately extend the acceptance time of slope ecological restoration to 3-5 years after handover and acceptance.

4.3. *Recommendatory Measures and Suggestions*

Plan-Do-Check-Action (PDCA) method should be used through the life cycle. In the design stage, the principle of dynamic design should be implemented and the technology should be selected according to local conditions. In the construction stage, the material access is strictly implemented and the quantitative index control is strengthened. In the inspection stage, the self-inspection of the contractor should be strengthened [15]. In the improvement stage, the existing unreasonable protection and greening shall be adjusted.

4.4. *Guiding Measures and Suggestions*

(1) Slope ecological restoration standards should be compiled. The standards are based on the practice of slope restoration projects and local standards in some provinces and cities.

(2) The propaganda about slope ecological restoration should be enhanced. With the theme of establishing ecological restoration of slopes, policy advocacy and technical exchanges should be carried out in forums and conferences such as green transportation, green highways and slope restoration

5. Discussion and Outlook

Based on the three characteristics of green highways, namely “low consumption, low emission and low pollution”, “high efficiency, high effectiveness and high efficiency” and “whole life, whole elements and all-round”, and the eight ideas including “no damage is the greatest protection” and “intensive and economical use of resources”, this paper explores the five development directions of slope ecological restoration from the perspective of green highways. Slope ecological restoration management suggestions are put forward from four perspectives of encouragement, compulsiveness, recommendation and guidance, to provide directional guidance and management countermeasures for the development of slope ecological restoration in the new era.

The problem of slope ecological restoration still exists, such as high proportion of engineering hard protection, high price of new materials, improper selection of plants, and poor restoration effect. With the increasing emphasis on the restoration of ecological environment, the protection of concrete engineering in highway construction will continue to decrease in the future. Using seed bank of topsoil resources to restore slope plant community is the future research direction. It is also a trend to develop and study new, fast, durable and cost-effective slope ecological restoration technologies.

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