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Mountain Highway Design based on Natural Environment Protection

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Abstract: During the construction of expressway, the excavation of slope destroys the original landform, blocks the hydrological network in the region, and easily causes water and soil loss, which not only damages the local ecosystem, but also affects the road operation. Therefore, it is of great significance to study the optimization design of the subgrade slope of mountainous expressway and the protection of the natural ecological environment. This paper discusses the optimization design of mountain expressway(ME) based on natural environment protection(NEP). The characteristics of ME slope and the coordinated development of NEP and ME are briefly analyzed; This paper analyzes the role of NEP in the optimal design of MEs, and probes into the optimal design of MEs; This paper comprehensively evaluates the quality and effect of ecological protection(EP) project for subgrade slope of ME from four aspects of slope protection function, ecological benefit, landscape effect and construction situation, and verifies the effectiveness of the optimized design of ME based on NEP proposed in this paper.

1. Introduction

During the highway construction in mountainous and hilly areas, how to minimize the damage to the environment caused by the construction, restore the road ecology as much as possible, and provide a fast and comfortable driving environment for the people has become a problem that needs to be solved emphatically during the highway design and construction. It is an important problem how to select effective protection technology in highway construction according to the characteristics of highway construction in mountainous areas, so as to perfectly combine slope reinforcement benefits with ecological benefits. Therefore, this paper discusses the optimal design of ME based on NEP.

The optimal design of ME based on NEP is the earliest application in EP. Since the 20th century, people have paid more and more attention to environmental protection, so the application of EP technology has become more and more. Scholars have conducted a lot of research on it. Europe,

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America, Japan and other developed countries began to pay attention to environmental protection issues in highway construction very early. For example, the United States used EP technology in the "crown of angels" highway in California [1]. Developed countries have long incorporated slope protection and greening into highway design, formulated design principles, summarized construction standards and measures, and sorted out norms and regulations. The expressway construction in China started in the late 1990s. At the beginning, due to lack of environmental awareness and experience, and insufficient understanding of the shortcomings of engineering protection, most of the slopes used mortar rubble, face wall and other engineering methods, which not only damaged the local ecological environment, but also generated high maintenance costs. With the development of social economy, people have more and more requirements for environmental protection, emphasizing the harmonious development with nature, and the research on slope protection technology has begun to turn to EP technology [2].

Based on literature summary, field investigation, indoor test and engineering practice, this paper studies the adaptability of subgrade slope protection technology, sand slope solidification, and comprehensive evaluation methods of EP projects of expressway in mountainous areas. Sort out the existing subgrade slope protection technologies, refer to the characteristics of ME slope, and conduct applicability evaluation in three aspects: applicable area, slope surface characteristics, and technical effect. The evaluation system of EP effect of ME slope based on analytic hierarchy process and comprehensive index method is constructed. Finally, this evaluation model is applied to evaluate the high-speed slope protection project in Zhangcheng Mountain Area. The results show that the slope protection effect is very good, which verifies the availability of the optimization design model of ME based on NEP in this paper [3, 4].

2. Analysis of ME based on NEP

2.1. Analysis of Slope Characteristics of Mountainous Expressway

The slope of expressway in mountainous area is distributed in a belt shape and runs through many climatic regions. Generally, the expressway has a very long mileage and is distributed in strips, so it may pass through multiple climatic regions. When selecting slope protection technology, full consideration should be given to local climatic characteristics, and measures should be taken according to local conditions to obtain better protection effect; The landscape is broken and the rainfall is uneven [5]. The expressway cuts the complete local ecosystem, breaking the landscape along the way, which is not conducive to protecting the diversity of communities. The mountain terrain is complex. The elevation and the sunny side and the shady side of the mountain all affect the rainfall and sunshine. The sunny slope has strong sunshine intensity and severe temperature difference, which will affect the growth of plants. Therefore, the specific conditions of the slope should be considered in addition to the local climate when selecting the slope protection technology; There are many high and steep slopes. Deep excavation and high filling of expressways in mountainous areas produce many high and steep slopes, which are steep and difficult to afforest, and are prone to water and soil loss [6, 7].

2.2. Coordinated Development of NEP and ME

2.2.1. EP Technology

Vegetation belt greening: the vegetation belt is to mix the vegetation seeds with fertilizer, water retaining agent, etc. evenly, use special machinery to accurately spread them on the degradable non-woven fabric or wood pulp paper in proportion, and make them not easy to fall off through special processes. The vegetation belt can be laid on the slope surface to achieve the goal of vegetation restoration [8].

Process characteristics: the number of seeds and fertilizers in the planting belt is accurate, the distribution is uniform, the emergence rate is high, the emergence is neat, and the formation speed is fast; The planting belt has the functions of water conservation and heat preservation to a certain extent, and it can also prevent rain washing and improve the germination rate and speed of seeds; The planting belt can be produced in the factory, which is small in size, light in weight, simple in construction, time-saving and labor-saving; The vegetation belt itself is easy to degrade and pollution-free, and can be converted into fertilizer after degradation [9, 10].

Applicable conditions. It is mainly used in humid and semi humid areas, and can also be used in arid and semi arid areas when water source conditions are met; The common slope ratio is 1:1.5~1:2.0, and when it exceeds 1:1.25, other methods shall be considered; Stable slope not exceeding 10m generally; Generally, construction in the northern region should be carried out in spring and autumn. During construction, attention should be paid to rainstorm erosion and rain water erosion prevention measures should be taken. For autumn construction, the amount of fertilizer for vegetation to turn green through winter shall be designed [11].

Construction technology. The construction process of planting belt is shown in Figure 1.

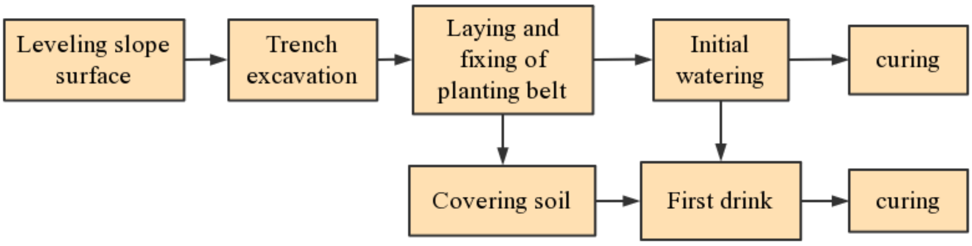

Figure 1. Construction flow chart of planting belt

Curing. After the construction is completed, spray water in mist form for a few times, preferably in the morning and evening. Apply fertilizer in a timely and appropriate manner to prevent diseases and insect pests.

Planting bags, grass planting and greening:

Technical characteristics. The structure of the planting bag is conducive to plant growth. It can keep heat and water, has high seed germination rate, and can also prevent rain erosion. It is convenient for later maintenance [12, 13]. Vegetation bag is a degradable material with ecological and environmental protection. It is convenient for transportation, simple in construction technology, and does not require large machinery. However, it requires a lot of manpower, slow in construction, and high in cost.

Applicable conditions. It is applicable to all kinds of slopes. The slope ratio is not steeper than 1:0.5, and it is widely adaptable to climate [14].

Construction technology. The construction process of planting bag technology is shown in Figure 2.

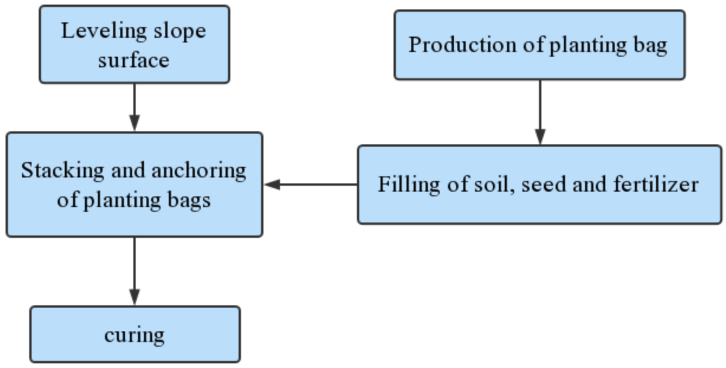

Figure 2. Construction flow chart of planting bag technology

2.2.2. High and Steep Slope EP Technology

During the construction of expressway, when encountering mountainous areas with extremely complex terrain, high excavation and high filling will form many high slopes and superelevation slopes with a gradient of more than 1:0.5. Due to the height of high and steep slopes, there may be stability problems in the deep layer of the slope. The protection must be combined with the reinforcement technology, and the slope surface is steep. The shallow soil is difficult to fix on the slope surface, easy to slip, and difficult to retain water, which affects the growth of vegetation. When covering the soil, some engineering measures should be taken to ensure the stability of the soil and the slope, and the soil with good water retention and drought resistant plants should also be selected [15, 16].

2.2.3. Slope Protection with Vegetation Filled in Reinforced Concrete Frame

Use concrete to form a frame on the slope surface, fill the frame with foreign soil, and use some techniques to fix the foreign soil so that it can be planted with grass to protect the green slope surface of the slope. This protection technology is called reinforced concrete frame grass planting slope protection [17]. It has stronger reinforcement effect than skeleton grass planting slope protection, but the project cost is higher. It can be used in various slopes, but because of economic factors, it is usually only used in high and steep rock slopes [18].

3. Optimal Design of ME Based on NEP

3.1. Analysis of the Role of NEP in the Optimal Design of ME

3.1.1. Mechanism of Vegetation Slope Protection

Vegetation protection mainly depends on the stems, leaves and roots of plants to play a protective role, so its role can be divided into two aspects: hydrological effect of vegetation and mechanical effect of roots, as shown in Figure 3.

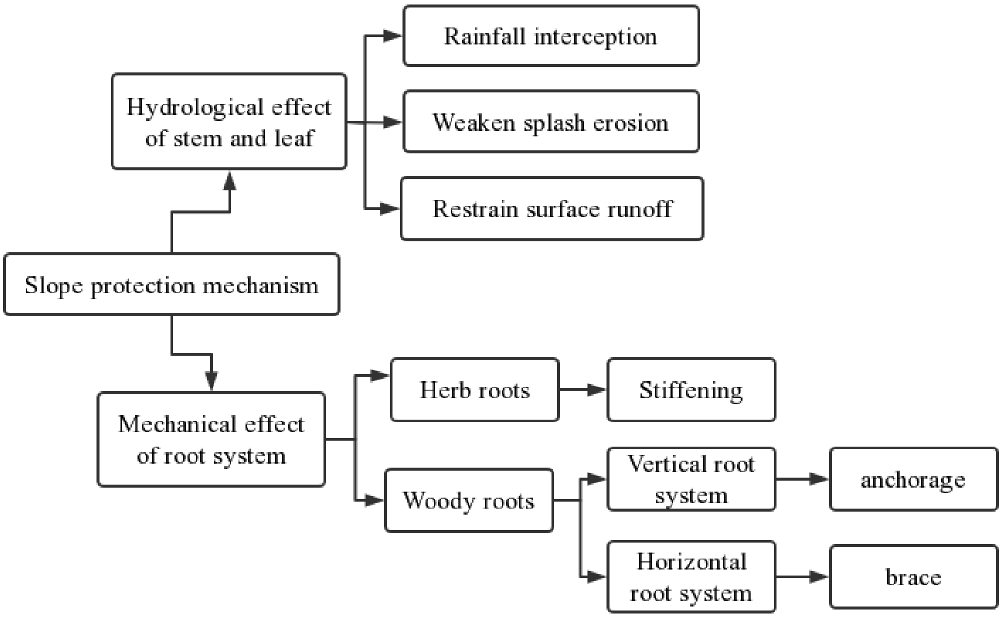

Figure 3. Mechanism of vegetation slope protection

Hydrological effect of vegetation:

Rainfall interception by vegetation. Vegetation grows on the slope surface, and its branches and leaves as well as the dead branches and fallen leaves on the slope can block part of the rainwater, and then the rainwater evaporates or falls back on the slope, which can reduce the erosion of rainwater on the slope, thus playing a protective role. The rainfall intercepted by vegetation can be derived from the following process. Assume a closure coefficient λ， Make interception rainfall E and rainfall P meet the functional relationship:

$$E(P) = \lambda(P) \cdot P \tag{1}$$

For the determined vegetation, the maximum coverage veg, its leaf area index LAI and the maximum rainfall interception are constants, which are determined by the following formula:

$$E' = a \cdot veg \cdot LAI \tag{2}$$

Where λ' Is the maximum interception coefficient, which is the vegetation coverage, namely λ'= veg。 If the ground is completely covered by vegetation λ'= 1, otherwise λ'< 1。

veg is the slope of the linear part, and its value range is 0~1. When the vegetation coverage decreases, the veg and will decrease, but the critical rainfall will not be affected.

The function of vegetation to weaken splash erosion. Raindrops fall on the slope during rainfall, and their kinetic energy splashes soil particles on the slope, causing turbulence of soil layer runoff. This is a form of water erosion, called splash erosion of raindrops. Data shows that soil particles can be splashed 60cm high by raindrops and fall 160cm away, which is very easy to cause water and soil loss.

If the slope is covered with vegetation, raindrops will be blocked by the branches and leaves of plants and the dead branches and leaves at the bottom when it rains, reducing the kinetic energy of raindrops, slowing down their impact on the slope, so as to play a role in weakening splash erosion. Through simple quantitative analysis, we can more intuitively understand the weakening effect of plants on the kinetic energy of raindrops.

3.2. Optimization of ME based on NEP

3.2.1. Environmental Protection Measures

Air quality protection measures during construction The mixing process of the project is plant mixing, so the links that cause air pollution focus on the loading and unloading of materials and the mixing process. Therefore, the mixing station and stock yard are designed to be 300m away from the downwind. At the same time, during the transportation, loading and unloading of bulk materials, shielding should be used to reduce dust.

For cement mixing, bridge works, unpaved construction roads and other environments prone to dust, water shall be sprayed regularly. The advantages of this device are obvious: high pollution removal efficiency, small floor area, about 15m2 for each service area, and about 6m2 for each parking area; The noise generated by the setting is small, and the operation is convenient.

3.2.2. Groundwater Environment Protection Measures

Water environment protection measures during the design period. The construction of the line passing through the Jingquan catchment area of Xiahuayuan has a certain impact on the water quantity and quality of the water intake point. It is recommended to strengthen the hydrogeological drilling and investigation work in this area. Under the condition of meeting the engineering design specifications, the line should be shifted to the north as far as possible to minimize the impact on the water intake point; The bridge foundation piles in the Jingquan section of the line passing through Xiahuayuan should be located as far away from the water intake point as possible to avoid the impact of project construction on the water intake point; The layout and drainage of tunnel portal shall be strictly designed.

Water environment protection measures during operation. During the operation period of the Project, the road runoff flows through the drainage ditches and enters the surface gullies, instead of directly entering the springs along the line. Therefore, the road runoff during the operation period will not adversely affect the wells along the line; Under normal circumstances, during the operation period of the Project, the wastewater from the facilities along the line is not treated well with integrated water treatment equipment, which affects the groundwater quality; Well spring protection measures in the lower garden during the operation period. As this line is close to the centralized water intake of Xiahuayuan Bridge, in order to avoid the impact of accident sewage on the water source protection area, protective measures shall be added to the engineering measures in the catchment area of the centralized water intake of Xiahuayuan Bridge during the operation period. Including: the Xiahuayuan Bridge is equipped with a deck runoff system and an emergency pool on both sides of the bridge head. At the same time, the bridge is equipped with enhanced crash barriers and signboards on both sides to remind passing vehicles to slow down and drive cautiously; Side ditches for seepage prevention and drainage are set in the tunnel, and emergency pools are set on both sides of the tunnel.

During the operation period, the following measures can be taken to protect the acoustic environment. Necessary noise reduction measures shall be taken for the sensitive points with excessive noise in the predicted environmental sensitive points; Warning signs shall be set up when passing through densely populated areas, and sound barriers can be set up when necessary. Regularly inspect and maintain the pavement.

4. Discussion on Optimal Design of ME based on NEP

In order to verify the effectiveness of the optimized design of ME based on NEP proposed in this paper, this paper mainly conducts a comprehensive evaluation of the quality and effect of EP project of ME subgrade slope from four aspects: slope protection function, ecological benefit, landscape effect and construction situation. The evaluation system is divided into three levels: target level, criterion level and indicator level.

Target layer: evaluation of EP quality of subgrade slope of mountainous expressway; Criteria layer: slope protection function, ecological benefit, landscape effect and construction; Indicator layer: slope protection function indicators: root development, root influence range, anti scouring performance, interception rate; Ecological effect indicators: vegetation coverage, vegetation resistance, species diversity, biomass, number of native plants; Landscape effect indicators: ornamental, coordination with the surrounding environment, green period; Construction indicators: economy and construction difficulty.

4.1. Example Application

This paper attempts to evaluate the EP effect of the slope greening project in K88+255 section of Zhangcheng Expressway. The region belongs to the continental climate of the eastern monsoon northern temperate semi humid region. The data shows that the annual average temperature is 8.8 ℃, the highest temperature is 41.5 ℃, and the lowest temperature is - 23.3 ℃; The maximum height of the slope in this section is about 22.4m, which is divided into three grades, with a slope ratio of about 1:0.75. The slope is of all soil, good integrity and stable.

4.2. Protection Scheme

The slope is relatively stable, and the exposed slope is soil, so there is no problem of weathering and falling off of rock mass, but the slope rate is relatively steep. Therefore, the selected protection method is thick layer base material spraying for slope protection. The ratio of greening base materials is 80% of sandy loam soil, 8kg/m2 of organic fertilizer, 4kg/m2 of compound fertilizer, 1.0 ‰ of water retaining agent, 50kg/m2 of straw, and 1.0 ‰ of pelleting agent. The grass and shrub combination is adopted for spraying vegetation, and the specific types and proportions are shown in Table 1.

Table 1. Establishment and application of evaluation model of EP project effect

Plant classification	Plant name	Family	Spraying amount/ (g · m − 2)
Vegetation	Green bristlegrass	Poaceae	4.0
	Alfalfa	leguminous	2.0
	Perennial ryegrass	Poaceae	5.0
	Corolla variabilis	leguminous	1.0
	mother chrysanthemum	the composite family	4.0
shrub	bush clovers	leguminous	2.0
	Caragana	leguminous	3.0
	desert false indigo	leguminous	1.0
	Wattle	Verbenaceae	3.0

4.3. Slope Effect Evaluation after Protection

One year after the construction, the slope has been covered with vegetation, and herbs grow well, but there are not many shrubs, which should not have reached a stable growth period. The field survey and test values of each indicator are summarized as shown in Table 2.

Table 2. Scoring table for one-year slope protection effect

evaluating indicator	Index weight	Survey detection value	Score value	Evaluation value
Root development	0.088	Roots well developed	6	0.529
Root influence range/cm	0.051	28.21	4	0.204
Erosion resistance/%	0.148	8.24	10	1.486
Retention rate/%	0.030	41.33	8	0.242
Vegetation coverage/%	0.079	91	10	0.79
Vegetation resistance	0.161	Strong	8	1.293
Species diversity	0.052	0.83	8	0.416
Biomass	0.055	high	10	0.552
Number of native plants/%	0.041	43	6	0.250
Ornamental	0.070	preferably	8	0.562
Coordination with surrounding environment	0.032	preferably	8	0.260
Green period/d	0.013	220	6	0.079
Economy	0.114	preferably	8	0.912
Construction difficulty	0.057	More complex	4	0.228
Evaluation value				7.807

It can be seen from the above figure that the evaluation value of EP effect of optimized design of ME based on NEP is S=7.8078, and the evaluation grade should be good. Considering that 7.8078 is very close to 8, it can be seen that its protection quality effect is very good. On the basis of NEP, this paper gives the optimal design of ME. Use the analytic hierarchy process to calculate the weight of each index, and then use the comprehensive index method to obtain the evaluation score of the protection project, according to which the final evaluation grade can be obtained. Finally, it is applied to the slope protection project of Zhangcheng Expressway to verify the availability of optimal design of ME based on NEP.

5. Conclusion

Due to the objective limitation and the limited level of the author, the optimization of ME based on NEP studied in this paper still has some problems to be further improved and worth studying. The selection of evaluation indexes for EP effect of slope is not comprehensive enough, and its economic value is not fully considered in ecological benefits; This paper only evaluated the protection effect one year after the completion of a slope protection project of Zhang Cheng Expressway. The selected indicators were not refined enough, and the stability of the model was not verified. If time permits, the long-term vegetation evolution process can be tracked, and the protection effect three years and seven years after the completion of the project will be evaluated and compared. Further research is needed on the optimal design of mountainous highways.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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