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Review

REVIEW

Research progress on ecological protection technology of highway slope: status and challenges

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Abstract

Slope protection has always been a major concern in highway construction and later operation. Ecological protection technology is widely used in highway slope, which takes into account functions of protection, ecology, and landscape. Ecological protection technology is mainly to improve the stability of the slope through the combination of supporting structure and plants, and vegetation restoration can reduce the negative impact of highway construction. In this paper, the latest research progress of ecological protection technology was first reviewed to identify the main construction process and types, which revealed the protection mechanism of ecological protection technology. The comprehensive benefits of ecological slope protection technology were analysed from the aspects of air, water circulation, landscape and biodiversity. It has found that ecological protection technology of highway slope mainly forms the atmosphere-plant-soil system. Ecological protection technology of highway slope improved the stability of the slope through the supporting structure and the anchoring effect of plant roots. And the restoration of the surface vegetation on the slope promoted the photosynthesis and transpiration of plants and purifies the air quality along the highway. Ecological protection technology of highway slope could quickly restore the ecological balance, overall landscape and biodiversity of the region.

Keywords: ecological protection; protection mechanism; ecosystem; biodiversity; overall benefit

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1 Introduction

Due to the rapid economic and social development in China, transportation infrastructures are developing quickly. There has been 143 000 kilometers of highways in China, which has become the longest highway country in the world by 2019. With the full implementation of the 'Belt and Road' and 'National Highway Network' strategies, a huge country highway network consisting of '7 radiations of the capital, 11 north-south vertical lines, 18 east-west horizontal lines' will be formed in China. Highway construction has accelerated economic exchanges in various regions of our country and promoted the rapid development of our economy. However, during the construction and operation of highways, human activities (e.g. excavation, filling, dumping and automobile exhaust emissions) are bound to have a profound impact on the areas along the highway (Fig. 1) [1–4]. The construction of the highway has caused a large number of exposed slopes along the highway [5, 6]. Slope excavation has changed the original stress state and reduced the stability of the slope [7, 8]. Under the influence of natural climate (e.g. rainfall, weathering and dry-wet cycles), runoff is easily generated on the slope surface. It leads to the rock and soil on the slope surface being scoured and a large amount of water and soil loss [9, 10]. In extreme conditions, it even leads to landslides and mudslides. The safety of people's lives and property will be greatly threatened [11, 12]. Highway construction has also devastated the surface vegetation of the slope and changed the natural landforms along the highway [13–15]. It has caused the habitats of animals and plants to be artificially divided and destroyed, leading the original ecosystem to be destroyed [16–18, 19]. During the construction and operation of the highway, humans (excavation, laying and drilling, etc.) have added a large amount of solid particles to the atmosphere [20, 21]. After being washed by rainwater, it will be discharged into the soil, rivers and lakes along the highway through groundwater or surface runoff, leading to the water system along highway being polluted [22, 23]. As motor vehicles continue to increase on highways, the exhaust gas from cars aggravates the pollution of air, soil, rivers and lakes [24, 25, 26]. Therefore, whilst carrying out highway construction, attention should be paid to avoiding or reducing the negative impact of highway construction on the areas along the highway.

Slope protection is an important link in highway construction, and the protection effect will directly affect the safety of highway operations and the balance of the ecosystem along the highway. The traditional slope protection methods are mostly rigid and flexible protection. In terms of protection concept, more consideration is given to the safety of structural and hydrogeological conditions, whilst neglecting the construction of soil and water conservation, landscape esthetics and slope ecological protection [27] confirmed that the traditional slope protection methods could improve the stability of the slope and prevent landslides and debris flows. However, it is difficult to restore natural vegetation, and it is not conducive to the protection of the ecological environment and soil and water conservation. After adopting flexible protection and rigid protection, the appearance of highway slope was relatively simple and not consistent with the surrounding landscape in most cases [28]. Most of the materials used in traditional protection methods were cement, concrete and steel, which were not renewable [29]. The heavy use of cement and concrete would inevitably cause the soil to harden and saline-alkali problems on the slope. This was extremely detrimental to the growth of animals, plants and microorganisms. During the production of cement and steel wire mesh, a large amount of harmful gases (e.g. CO_2, SO_2 and NO_2) and dust was generated [30]. This is not in line with the theme of sustainable development today. Therefore, the traditional slope protection methods are increasingly restricted in engineering construction.

In recent years, due to the increase of environmental protection, the restoration of ecosystems along highways has received more and more attention. As a new method of slope protection, ecological protection technology has attracted the attention of a large number of traffic engineering builders. It showed that ecological protection technology could effectively prevent and control slope soil erosion and shallow landslides and reduce the degree of slope soil cracking. The restoration of surface vegetation effectively increased the stability of the highway slope, and promoted rapid restoration of the ecosystem along the highway [31]. In this article, the application progress of ecological protection technology of highway slope is summarized, and the basic principles and slope protection steps of ecological slope protection technology are elaborated. Ecological protection technology of highway slope was classified from the initial protection methods. It also revealed the slope protection mechanism and discussed the ecological benefits of ecological slope protection technology.

Fig. 1. Impact of highway slope construction

2. Ecological slope protection technology

Ecological protection technology was widely used to reinforce riverbank and restore ecological of barren mountains. Due to the importance of ecological environment to the highway construction, ecological protection technology has been gradually applied to slope engineering. It has been combined with traditional protection technology to form a new ecological slope protection technology. Ecological protection technology has been applied in developed countries. Moorish R.H. analysed the effects of turf planting time, types and combinations of grass species on the protection highway slopes [32]. Subsequently, McElroy M.T. carried out a systematic study of the slope protection effect of plants in 1986 and gradually improved the slope protection system [33]. Although a single plant protection of slope could restore slope vegetation and rebuild a new slope ecosystem, its impact on slope stability was weak, and natural disasters such as landslides and debris flows could not be completely eliminated. The combination of traditional slope protection and plant slope protection could make up the deficiency of the single slope protection method. It proved that the comprehensive protection measures are superior to the single plant protection measures by using the slope protection fabric and plants to protect the slope [34]. Medl *et al.* [35] believed that geogrids and plants protect the high steep slopes and contribute to the restoration of biodiversity and ecosystem on the slopes [35]. The research on ecological slope protection technology was relatively late in China, but it has developed rapidly, especially since the 21st century. With the continuous emphasis on the ecological environment in China, great achievements have been made in ecological protection technology of highway slope.

At present, the ecological slope protection technology mainly uses the civil structure or materials to carry out the initial treatment of the slope and then uses the method of plant slope protection to reduce the soil erosion on the slope surface and restore the ecological environment. Fig. 2 shows the specific steps of ecological protection technology of highway, and the details are as follows:

2.1 Treatment of slope surface

There were a lot of broken rock and soil bodies on the slope surface after excavation, and the slope is uneven, which greatly affects the later support. Therefore, the surface of the slope after the excavation needs to be leveled to build the necessary drainage facilities. If the slope height is too high, you need to divide the slope into several steps.

2.2 Preliminary bracing

The support methods play an important role in the stability of the slope. There are many types of support methods. Each support method has different protection effects on the slope. Therefore, proper support needs to be adopted according to the slope's geology, slope height and slope ratio.

2.3 Vegetation choice

Vegetation plays a decisive role in the later restoration of the ecosystem, and each plant has differ-

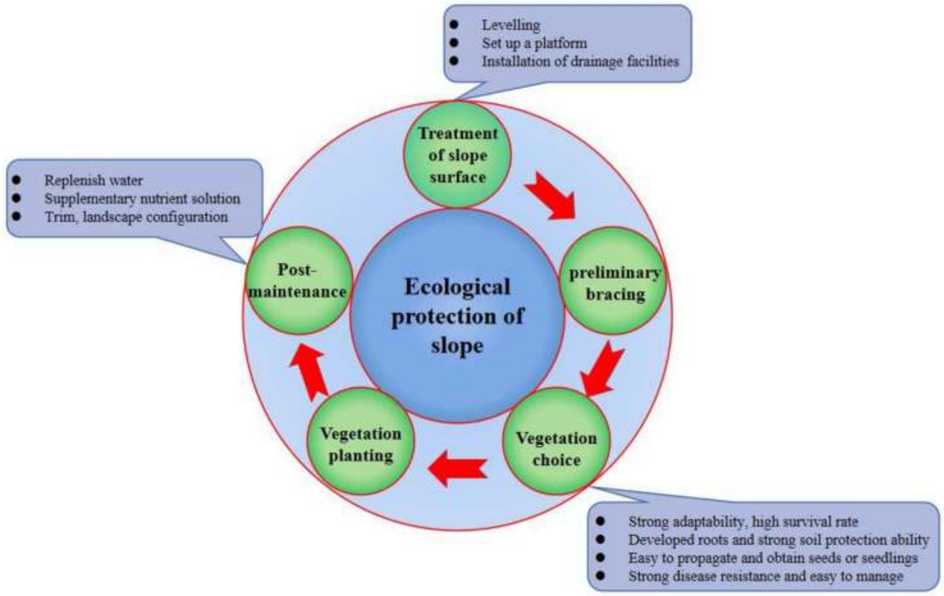

Fig. 2. Ecological slope protection process

ent climate requirements. Therefore, plant species should be determined according to the local climate. At the same time, plants also need to meet the following requirements:

① Strong adaptability and high survival rate.
② Developed roots and strong soil protection ability.
③ Easy to reproduce and easy to get seeds or seedlings.
④ Strong disease resistance and easy management.

2.4 Vegetation planting

The spray seeding technique is generally used at this stage.

2.5 Post-maintenance

After the vegetation is planted, the vegetation needs to be regularly replenished with water and nutrients. Besides, the plants must be trimmed to reduce the impact on the driving of the car and ensure the beautiful scenery along the highway.

3. Classification of ecological slope protection technology

In recent years, due to the wide application of new environmental protection materials in the field of civil engineering, ecological protection technology of highway slope has developed rapidly. A large number of new technologies with satisfactory protection effects have emerged, such as ecological concrete protection technology, geotextile protection technology and biological enzyme protection technology. According to its preliminary bracing method, ecological protection technology could be divided into physical protection, biological protection and chemical protection (Fig. 3).

3.1 Physical protection of slope

Physical protection of slope mainly protected the slope through preliminary bracing of the slope through geotechnical materials (ecological concrete, geotextiles, ecological bags, etc.). Physical protection of slope mainly included ecological concrete protection, geotextile protection, ecological bag protection, self-embedded retaining wall protection and concrete frame protection [36–39]. Ecological concrete protection, geotextile and concrete frame protection were used most widely. In terms of ecological concrete slope protection,Broda, J., *et al.* reported the impact of ecological concrete on the growth of native grassland species (e.g. trinidad, green chafer and rhododendron). It obtained the effects of fly ash on the growth of native grass species [40]. The content of concrete has a significant effect on seed germination and seedling growth, and the content of concrete suitable for seed germination and seedling growth is 8% [41]. Because ecological concrete has good compatibility with the ecological environment, it has an active role in promoting vegetation restoration and biodiversity. It proved

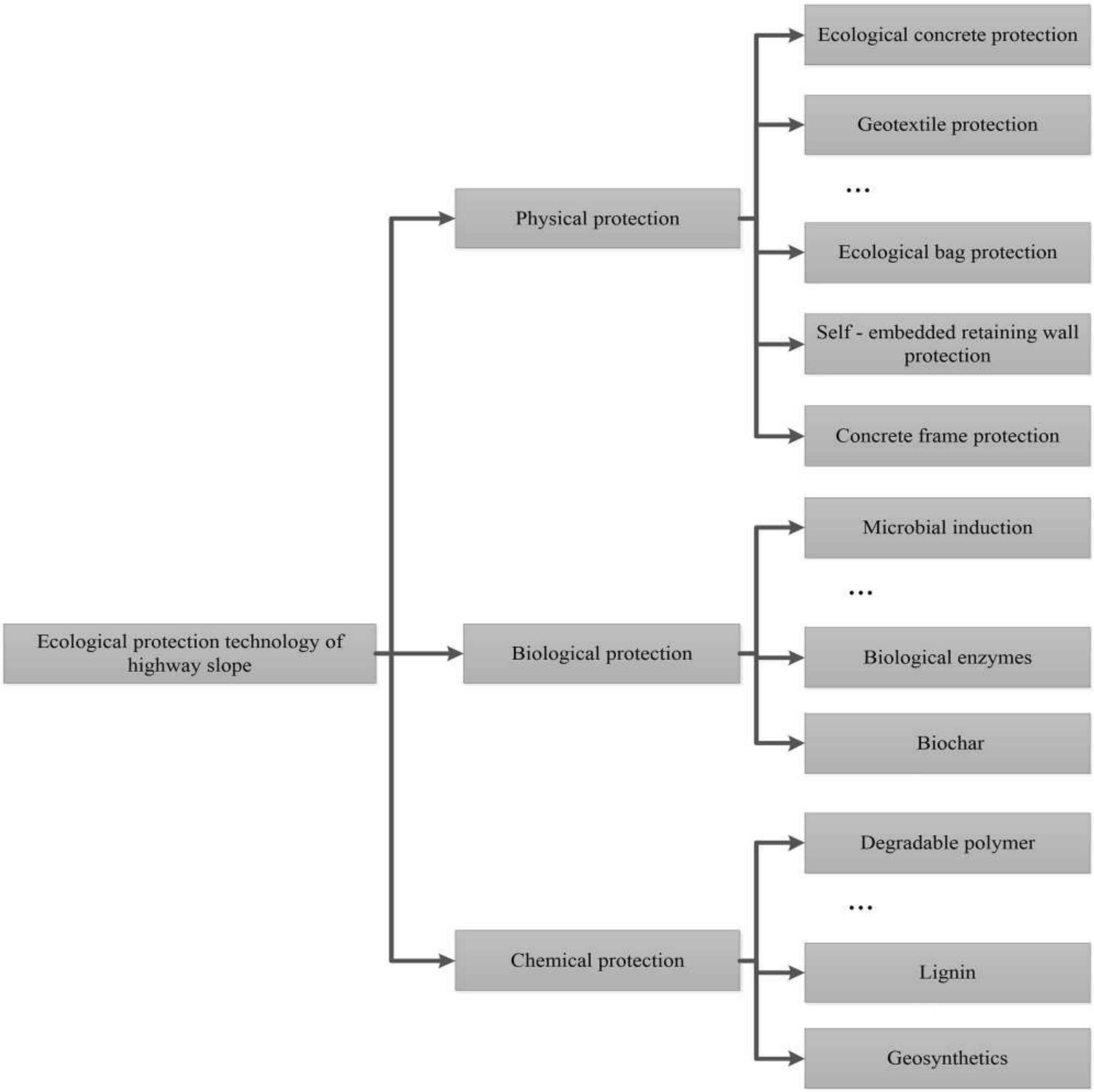

Fig. 3. Classification of ecological protection technologies

that the ecological concrete also has a good effect on water and soil retention, bank revetment and slope revetment, landscape restoration, and so on. However, its shortcomings are still significant. Therefore, it needs to seek new protection of slope.

Geotextiles can effectively prevent soil erosion on the slope surface and improve the mechanical properties and permeability of the surface soil. However, geotextiles prevent contact between plants and soil, thereby reducing the growth of coconut palm vegetation [42, 43]. Feng *et al.* [44] found that there were significant differences in vegetation growth, soil erosion, and improved stability under different slopes and vegetation types [45]. Luo *et al.* [11] reported that the three kinds of geotextiles (i.e. shade net, non-woven fabrics and straw mats) all significantly ($P < 0.001$) decreased runoff and sediment concentration compared with the bare slope. Furthermore, straw mats had the best effect amongst them, resulting in the lowest runoff coefficient (10.9%) and sediment yield (8.5 g m^{-2}) [46]. Comparing with traditional cementitious material (e.g. shotcrete), the concrete canvas is more suitable for the rapid and severe

Fig. 4. Effect of concrete frame beam and plant slope protection

(e.g. rainstorm) construction of slope [47]. It also found that concrete frames had great advantages in improving the stability of slopes. The concrete frame with the plant slope protection had a very beneficial effect in preventing slope collapse and landslides [48, 49, 50]. Our team also carried out research on this aspect and successfully applied concrete frame beam and plant slope protection to the highway slope form Yiyang to Loudi, Hunan Province, and achieved good results (Fig. 4). Although the physical slope protection technology can effectively improve the stability of the slope, it also has great limitations. Due to the mechanism, the construction difficulty and the protection effect of each protection method were different, so the scope of application was also different. This paper analysed the advantages and disadvantages of six protection methods of slope and determined the applicable scope of each method (Table 1). In practical engineering, the appropriate ecological protection technology according to the characteristics of the slope and Table 6 could be selected.

3.2 Biological protection of slope

In biological protection of slope, microbial induction, biological enzymes and biochar are often used to change the physical and chemical properties of slope soil matrix and promote plant growth [51–53]. Microbial induction is mainly through the biological control mechanism and the biological induction mechanism to promote the release of biological enzymes by the microorganisms and then use the biological enzymes to improve the soil. During the process of microbial induction, the extracellular metabolic activity of microorganisms mainly depends on environmental conditions [54]. Harkes *et al.* [55] analysed the effect of urease content in bacteria on urea decomposition and the formation of calcium carbonate precipitation. It found that the precipitated calcium carbonate combined with soil particles, which caused the soil to harden and fill the pores. The filling of internal pores in the soil could increase the strength of the soil and reduce the soil's permeability coefficient [55]. Stabinikov *et al.* [56] discussed the method of treating sandy soil with a mixture of calcium salt urea and bacterial suspension [56]. The formation of calcium carbonate induced by microorganisms can lead to the formation of a water-tight and high-strength hard shell layer, resulting in a significant reduction in permeability, and the strength is significantly improved. It studied that microbial induction could effectively enhance the strength of the soil on the slope surface and improve the stability of the slope.

Table 1. Comparison of six common physical protection technologies

Slope protection method		Advantage	Disadvantage	Scope of application
Geotechnical material composite planting protection	Net mats, planting soil and grass seeds	Good soil fixation effect, strong erosion resistance, economic and environmental protection	Weak anti-rainstorm ability	Not suitable for areas with heavy rainfall, steep slopes
	Geotechnical unit planting base	Light material, wear resistance, aging resistance, good toughness, strong impact resistance, convenient transportation, convenient construction method, and can be used multiple times	Greatly affected by slope	Not suitable for areas with heavy rainfall, steep slopes
	Geogrid	Strong erosion resistance, low cost, convenient transportation, simple construction, short construction period	Poor anti-aging ability, flammable	
Ecological gabion protection		Strong integrity, water permeability, erosion resistance, and ecological suitability, it has a wide range of applications, it is conducive to the growth of natural plants and improves the bank slope environment, low cost, economical, and convenient transportation	Large amount of stone	Not suitable for plain areas
Vegetation-type ecological concrete protection		Provide a substrate for plant growth, good erosion resistance, high slope porosity to provide a breeding place for animals and microorganisms, high air permeability of the material to a large extent guarantees the ability of moisture and heat exchange between the protected soil and the air.	Alkali reduction issues, strength and durability to be verified, reseedability needs further verification, revetment prices are high.	
Eco bag protection		Strong stability, with water- and water-impermeable filtering function, conducive to rapid restoration of the ecosystem, easy and fast construction	Easy to age, regeneration of plant seeds in ecological bags. Eco bag with too large pores is easy to carry out the bag body under the wash of water, causing settlement and affecting the stability of the bank slope.	Mainly used for the construction of flexible ecological slopes
Porous structure protection		Various forms, and porous bricks with different shapes can be selected according to different needs, the pores of the porous bricks can be used for planting grass, and the underwater part can also be used as a habitat for fish and shrimp.	Grade of side slope must not be too large, otherwise the porous bricks are liable to slip, the slope must be firm, the soil needs to be compacted and compacted.	the cost is high, and the construction workload is large, not suitable for sandy soil
Self-retaining retaining wall protection		Save material, Variety of shapes, mainly curved, straight, landscape and vegetative, to meet the needs of different slope forms, low requirements on foundation, good seismic performance, easy construction, no noise during construction, and convenient for later removal	Large amount of stone and easy to cause convex corners	Suitable for areas with high walls, large slopes on the top of the wall, live loads or poor soil quality

Fig. 5. Plant growth on the slope after using tyranase for 1 year

However, the required conditions are difficult to control and difficult to operate in practical engineering, so it is not common in slope ecology. The fundamental reason for microbial induction is to obtain biological enzymes with improved soil properties. Therefore, directly applied biopolymers (e.g. xanthan gum, bacterial-glucan and guar gum) produced to slope protection can achieve the same effect as biological induction [57, 58, 59]. However, the increase of organic matter in soil is bound to lead to the increase of microbial activities, which may adversely influence the stress–strain properties of soils [60]. The main mechanism of biological enzyme slope protection is mainly through the formation of new chemical bonds between biological enzymes and soil particles; thus, a large bioenzyme-geotechnical aggregate is formed, and the surface soil permeability and biological compatibility are improved. Our team has also done a lot of research on the biological enzyme slope protection technology, and successfully applied tyranase to the highway slope protection and achieved good results. Fig. 5 shows the plant growth on the slope after using tyranase for 1 year.

Biochar has significant effects in improving slope soil and promoting vegetation restoration [61–63]. Two years after adding biochar, soil carbon and nitrogen had an upward trend and then a downward trend. Soil carbon increased the microbial biomass and promoted soil carbon and nitrogen cycling enzyme activities [64]. It was found that biochar enriched specific beneficial bacteria and reduced pathogenic bacteria by absorbing more carbon and nitrogen. It also effectively controlled the occurrence of bacterial wilt, whilst increasing soil activity and fertility [65, 66]. At present, biochar has been widely used in ecological slope protection technology, which has produced huge beneficial effects in soil structure, purification of pollutants and biodiversity.

3.3 Chemical protection of slope

Chemical protection of slope is to use chemical methods to improve the slope soil. Polymers, lignin and geopolymers were often used as chemical protection materials, which could reinforce the slope surface and enhance the nutrients in the slope soil [67–69]. High Performance-Flexible Growth Medium (HP-FGM) which composed of thermally processed wood fibers, biodegradable interlocking fibers, natural biopolymers and a microporous particulate base has excellent chemical and mechanical bonding properties. The main components are thermally processed wood fibers, biodegradable interlocking fibers, natural biopolymers and a microporous particulate base. The combination of the HP-FGM, biotic soil medium (BSM) and the slope surface roughening treatment is economical and environmentally friendly and can achieve relatively good vegetation recovery [70]. Tomar *et al.* [71] investigated the optimal combination of nano-silica and polypropylene fiber with clay soil. The intermixing of polypropylene fiber with the soil acts as a reinforcing material in binding the soil particles and the bridge effect of fiber reinforcement in soil impeded the further development of tension cracks.[72]. Although the polymer material could effectively improve the strength of the soil and increase the stability of the slope, the improved soil was easy to harden, which was a disadvantage to the vegetation growth. As an important component of plant cell wall, lignin could promote the carbon cycle of the ecosystem after being degraded by microorganisms. With the increasing depletion of energy, lignin has received widespread attention as a renewable energy source [73–76]. Lignin has been also widely used in civil engineering due to its excellent biological compatibility and mechanical properties [77]. Liu, Y., *et al*. evaluate the engineering performance of 11 Sulfur-Free Lignin (SFL) stabilized soil. A considerable improvement of the mechanical properties was observed, which increases with SFL content up to 12% [78]. Lignin also has excellent effect in strengthening silty soil, Zhang, T., *et al*. analysed the durability mechanism of lignin-stabilized silty soil under different adverse environments, and found that the addition of lignin significantly improved the strength and durability of natural silty soil [79–81]. As a green cementing agent produced from a geological origin or an industrial waste, geopolymers have been widely valued in recent years. It was found that geopolymers generated gelled products, enhanced the unconfined compressive strength of the soil and improved its mechanical properties [82]. Furthermore, the UCS of specimens that were stabilized using a geopolymer based on recycled glass powder (RGP) were increased in comparison to the unstabilized specimens [83]. Although chemical protection technology could improve the slope soil and increase its shear strength, some by-products generated might adversely affect the ecological environment. Therefore, it is necessary to select various protection technologies based on various factors.

4. Comprehensive benefits of ecological slope protection technology

The core of ecological slope protection is the formation of an atmosphere-plant-soil system, which is mainly composed of soil, water, plants, microorganisms and the atmosphere. First, the preliminary bracing improved the anti-sliding force of the slope, and the plant roots improved the mechanical properties of the slope soil, both working together to improve the stability of the slope. Second, vegetation of slope surface could prevent rainwater from directly washing the soil on the slope surface; it prevents soil erosion and reduces the infiltration of surface water. Afterwards, due to the transpiration of plants, a new balanced water circulation was formed in the slope. In addition, vegetation restoration prevented the internal evaporation of the slope from causing the slope to crack. Finally, after the dry branches and leaves of the plants fall, a new carbon cycle balance was formed after the microbial decomposition in the soil (Fig. 6) [84–88]. Ecological protection technology of highway slope not only plays a significant role in improving slope stability, but also the restoration of vegetation has a huge positive impact on air quality along highways, water circulation in slope ecosystems, landscape restoration and biodiversity.

4.1 Purified air

Traffic emission is an important source of air pollution, and harmful substances in exhaust gas seriously harm human health [89–91]. As a narrow passage, the highway could easily form a canyon effect. Especially in mountainous areas, the slopes on both sides of the highway blocked the circulation of air, and the pollutants emitted by the traffic were not easy to spread. It could enter the human body through the respiratory system whilst driving, which seriously threatens the driver health [92, 93]. Air pollutants directly affected intestinal epithelial cells and intestinal flora, damaged the integrity of intestinal flora, disrupted the normal metabolism of microorganisms and then affected human health [44]. Furthermore, iron-rich combustion- and friction-derived nanoparticles (CFDNPs) that were abundantly present in airborne particulate matter pollution could increase the risk of Alzheimer's disease [94]. Harmful gases and solid particles in the air can increase the pressure on the human lungs and destroy human lung functions [95–97]. In this paper, it counted

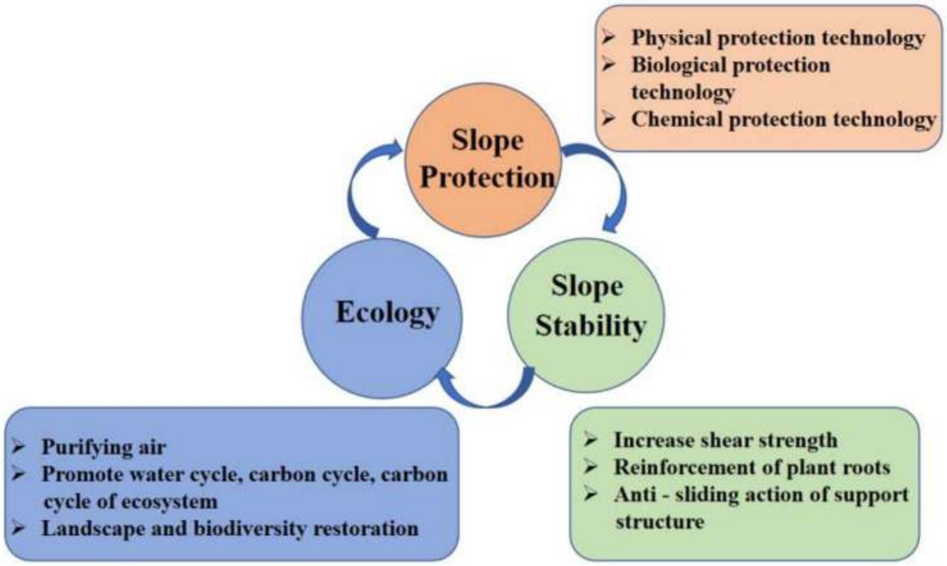

Fig. 6. Ecological slope protection mechanism

Table 2. Impact of partial exhaust gases and solid particles from automobile exhaust on human health

Pollutant	Harm
Solid suspended particles	After absorption, the human body will stay in the respiratory tract to stimulate the formation of malignant tumors. In addition, it will cause dermatitis, ocular conjunctivitis and even corneal damage.
Carbon monoxide (CO)	Harm the central nervous system, severely endanger the blood circulation system, leading to life danger
Nitrogen oxides (NO_x)	Mainly cause harm to the respiratory system, causing human respiratory dysfunction
Hydrocarbon (CH_x)	Reacts with nitrogen oxides, irritates eyes and upper respiratory tract mucosa, causing eye swelling and laryngitis
Plumbum (Pb)	Causes cardiovascular system diseases, and affects the function of important organs such as liver and kidneys, and the nervous system, especially the greatest threat to children

the impact of some polluted gases and solid particles from automobile exhaust on human health (Table 2) [98–100].

Plants could improve air quality and reduce the impact of traffic pollution through photosynthesis, carbon cycle and nitrogen cycle [101–103]. Firstly, plants absorbed the exhaust gas of vehicles driving on the highway, which could synthesize new substances in plants through photosynthesis. It promoted carbon and nitrogen cycles in the ecosystem. Furthermore, the solid micro-particles in the exhaust gas were combined with water vapor in the air to form free solid particles, some of which were deposited on the leaves and the road surface, and some of which are diffused in the air. After being washed by rain, they are deposited in the soil. Through the absorption of the plant root system, it re-enters the ecosystem, thereby forming a complete circulation channel.

4.2 Accelerated water circulation

Under the influence of various driving forces (e.g. solar radiation and the gravity of the earth), the various components of the water circulation were constantly moving, forming a global land-sea cycle [104]. The overall health of vegetation, the survival of certain species and the amount of aboveground biomass were largely dependent on the water circulation system, which were caused by a complex interplay of land and ocean evaporation, air circulation and local atmospheric stability changes [105]. The water circulation plays an important role in the ecosystem, and the smoothness of the water circulation directly affects the integrity of the ecosystem [106–109].

Under rainfall conditions, runoff would be generated on the surface of slope, which was formed due to the construction, and then it would cause a lot of soil and water loss on the slope. It dis-

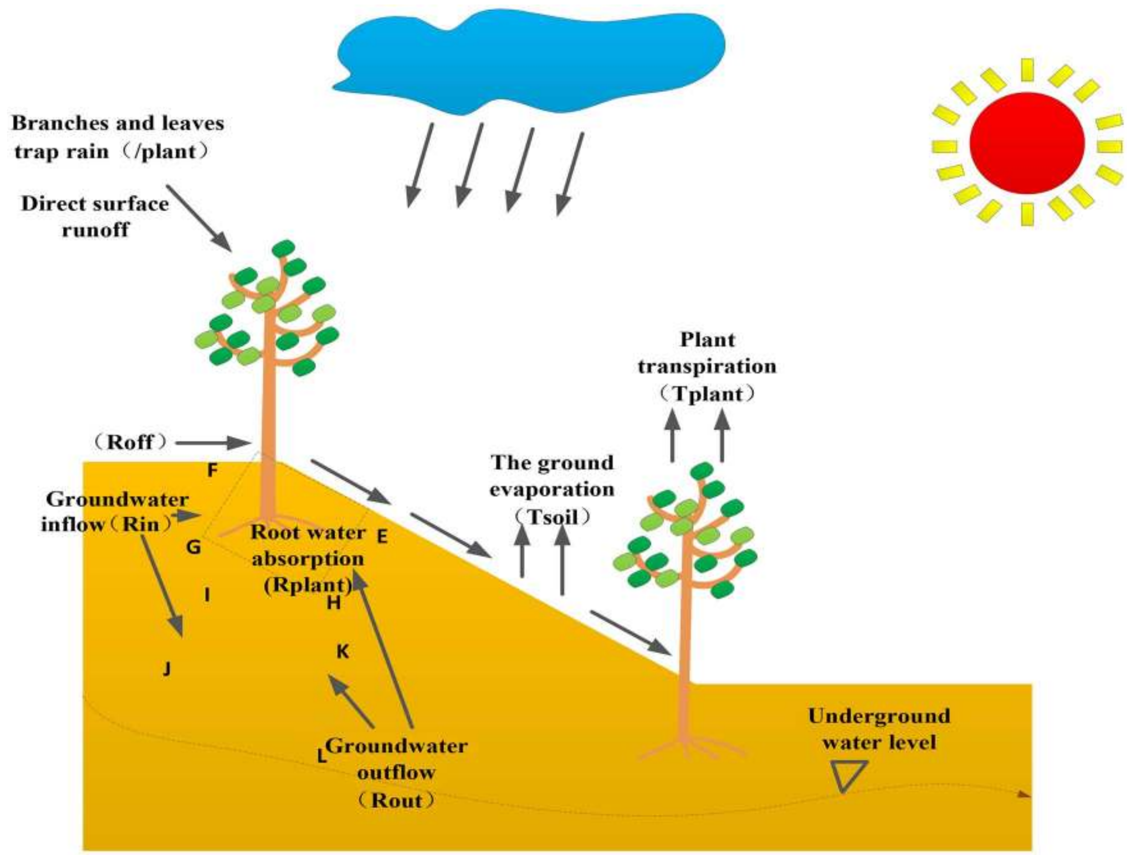

Fig. 7. Water circulation diagram of ecological slope

rupts the normal water circulation in the areas along the highway and causes extremely serious impacts on the ecosystems along the route. Vegetation restoration increased vegetation coverage, reduced soil erosion and promoted water resources cycling in the area [110–113]. Zhao *et al.* [114] supposed vegetation restoration played an important role in improving ecosystem service, such as controlling soil erosion and increasing carbon sequestration [114].

Fig. 7 shows the principle of the impact of highway ecological slope protection technology on ecological water circulation. First, plants prevented groundwater from eutrophication and recovered organic nutrients through removed nitrate and phosphorus from groundwater and filtered organics from groundwater. Secondly, vegetation prevents direct sun exposure to the soil and reduces evaporation in dry weather. After rainfall, transpiration accelerates the loss of water in the soil, thus forming a dynamic balance.

4.3 Impacts on landscape and biodiversity

Due to rapid highway construction development, the landscape and biological habitat along highway have been damaged, and it seriously affected the tourism value and ecological balance of the area. Exposed rock and soil could easily cause people to get into bad moods and psychological stress. Bucchi *et al.* [71] believed that psychological factors were an important factor in driving accidents [71]. Vegetation on both sides of the highway could help reduce driver stress and traffic accidents [115–117]. For forest highway, the restoration of vegetation on both sides of the slope would help enhance the overall landscape effect and increase the tourism value [118, 119].

The excavation of the slope caused the imbalance of the microbial system on the surface of the slope, and the habitats of animals and plants were destroyed. Due to the restoration of vegetation, microorganisms and animals and plants migrated from other areas to the surface of the slope. Borrelli *et al.*, [120] found that after the restoration of vegetation, they could provide microorganisms with new habitats and substances needed for survival, which greatly enriched the types of microorganisms. Meanwhile, the microorganisms promoted the circulation of nutrients, which could promote the growth of vegetation in the ecosystem though decomposed dead branches. The leaves and fruits of plants also provide a place for vertebrates to live and enrich the species of vertebrates [121].

5. Conclusions

Due to the rapid social development and environmental protection awareness, ecological protection technology of highway slope will be bound to be widely applied in the field of transportation. Ecological protection technology of highway slope is an extension of traditional protection technology. Compared with traditional protection technology, ecological slope protection technology takes into account ecological, landscape and protection requirements. Ecological slope protection technology has many advantages:

(1) Ecological protection technology can be used for both deep protection and shallow protection.
(2) The post-maintenance cost of ecological protection technology is much lower than that of traditional slope protection technology.
(3) Ecological protection technology has a huge positive impact on the air quality along the highway, the water circulation in the slope ecosystem, landscape restoration and biodiversity.

However, because of fussy construction, extremely high technical requirements and slow effect, the ecological protection technology of highway slope also has limitations. Therefore, future ecological slope protection technologies should focus on the following points:

(1) Whilst paying attention to the stability of the slope, it should be focused on the ecological and landscape benefits of ecological slope protection. Furthermore, the mixed planting of multiple plants should be comprehensively considered to form an overall landscape effect and enhance the tourism benefits of the area.
(2) Whilst pursuing landscape benefits, plants with short growth times should be selected to shorten the cycle of ecological protection.
(3) The ecological slope protection technology is further combined with engineering measures to develop a new and simple ecological protection technology of highway slope.
(4) Further improve the theory of ecological protection technology and formulate uniform evaluation standards.

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