Theoretical Study on Vegetation Restoration Ecology of Steep Slope

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Abstract. This paper applies the theory of ecology to discuss the effect of vegetation restoration on steep split slope by the vegetation form, the mechanical reinforcement of vegetation roots, the effect of vegetation root angle on soil stability of steep split slope, the effect of vegetation on erosion resistance of steep split slope. The favorable condition of vegetation restoration for steep split slope is explained in principle, and it provides theoretical reference for vegetation restoration of steep split slope.

1. Introduction
With the increasing demand for highway engineering construction, the construction of high-grade highways has begun to enter a large number of mountainous areas and economically underdeveloped areas, and the natural geographical environment is relatively fragile. However, accompanying these construction projects are ecological problems and even ecological degradation. During the construction of the expressway, the height and deep excavation of the subgrade slope need to destroy a large amount of original vegetation. It is easy to destroy the upper layer and the original nutrients during construction, making the original vegetation difficult to grow and forming a bare surface. Steep slope [1-3].

This paper uses the theory of ecology and mechanics to analyze the influencing factors of vegetation restoration on steep slopes and analyze the favorable conditions of vegetation restoration.

2. Influence of vegetation types on steep slopes
The tensile and compressive strength of the vegetation roots is generally higher than that of the soil. However, different types of vegetation have different growth habits and mechanical properties. The effects of planting different types of vegetation on steep slopes are also different [4].

2.1. The effect of herbaceous roots on the surface rock and soil of steep slope
A well-grown herbaceous plant whose roots are interconnected with the surface soil of the steep slope to improve the shear strength of the soil. The mechanical improvement of the root system to the soil is shown in Figure 1.

It can be seen from Fig. 1 that the herbaceous root system provides an additional "cohesion" $\Delta c$ to the soil layer, which increases the shear strength of the original soil by $\Delta c$, and the plant roots also limit the side of the soil. The expansion increases the stress in the soil to a constant extent, and the maximum shear stress of the soil is reduced. Under the combined effect of these two aspects, the roots of herbaceous plants effectively increase the bearing capacity of the soil. Most of the roots of
Herbaceous plants are mainly roots, and their growth depth is not large, 90% of them are distributed in the depth range of 0-30cm. The root system of the intrusive bedrock is less, and the bonding force between the weathered soil layer and the bedrock is weak, that is, a small amount of roots penetrate into the bedrock fissure, and when the soil water content is high, the roots of the herbaceous plant and the soil particles are The friction is rapidly reduced, and the reinforcement effect on the surface soil (weathering layer) of the slope is weakened, and it is easy to cause instability and collapse on the surface of the slope. Therefore, the root system of herbaceous plants is very weak in strengthening the surface rock and soil of the slope [5].

There are two problems in the landforms that use herbaceous plants to restore steep slopes: First, the roots of simple herbaceous plants are single, the effect of retaining weathered soil layers is poor, and the slopes are prone to collapse. Second, herbaceous plants are prone to decline. In particular, grass flower plants are more prone to decline and have poor persistence. After a growth cycle, the steep slopes of the slopes are often reappeared due to plant decay, making the process of ecological restoration of slopes difficult to continue, and continuous management measures are needed.

2.2. The reinforcement effect of roots of woody plants on the surface rock and soil of slope
The root strength of woody plants is significantly higher than that of herbs. The roots of woody plants grow deep and can penetrate deep into the bedrock fissures. In addition, the huge plant network formed by the roots of woody plants is protective against the surface soil or weathered layer of the slope.

Compared with herbaceous plants, woody plants have the following two advantages: First, the root system retains strong force, and the stability of the slope covered by herbaceous plants is strong, and it is not easy to cause slope collapse. The root system of woody plants not only has a long root length, but also has toughness, and the reinforcing effect on the soil is increasing year by year. Second, the woody plants are not easy to decline, the slopes after greening are not easy to slide, and the maintenance and management are small, so that the ecological restoration process of the slopes can be continued.

2.3. Relationship between vegetation type and steep slope
The slope of steep slopes has a great influence on the growth of vegetation roots. As the slope increases, the growth of vegetation roots may be completely different. This directly affects the stability of the soil on the surface of the slope.

The roots of herbaceous plants tend to extend downwards, and as the slope changes, their roots extend almost nowhere to the upper and upper layers. Therefore, when the slope becomes steep, the root distribution layer of the herbaceous plant becomes thinner. It can be considered that the slope becomes steep and the root distribution of the herbaceous plants changes from three-dimensional to two-dimensional plane when the slope is increased. Then the reinforcement effect of the root system on the surface of the slope is greatly reduced. When the slope of the slope exceeds 60°, the root system has not been able to strengthen the surface layer of the slope.
The distribution of roots of woody plants varies with slope, but is different from herbaceous plants. When the slope becomes steep, the roots of the woody plants still grow deep into the slope, which acts to reinforce the weathered soil layer. When the slope exceeds 60° or even reaches 90°, the roots of the red pine plant still extend to the deep and upper parts of the slope. It can still strengthen the weathering layer of the slope, as shown in Figure 2.

Figure 2. Changes of root morphology with slope of Pinus densiflora.

Different plant types are suitable for different slopes. Table 1 is the conclusion of foreign scholars on the investigation of different slope vegetation conditions.

| Plant growth | Below 30° | Arbor and shrub plants grow well. Ten plants in the countryside are easy to invade and erode after vegetation coverage. |
|--------------|-----------|------------------------------------------------------------------------------------------------------------------|
|              | 30~35 °   | The plant growth and development are vigorous, the shelving conditions are uncertain, and the boundary slope of whether the surrounding plants can naturally invade and form the community is 35 °. |
|              | 35~45 °   | The plant grows well and can form a plant community combining arbors, shrubs and herbs. |
|              | 45~60 °   | The growth of plants is poor, which can form a low plant community combining shrubs and herbs. High trees will cause slope instability. |
|              | Above 60° | The growth of plants is obviously poor, and herbs are prone to early decline. |

Due to the steep slope of the steep slope, many of them are above 60°, so it is not suitable to plant herbs. It is suitable to plant shrubs and short trees.

3. Vegetation root system to mechanical reinforcement of steep slope

3.1. The mechanical principle of vegetation root system for steep slope reinforcement

a. Rootless soil shear strength

The shear strength formula of undisturbed soil without plant root distribution is:

\[
S = c \tan \phi + \sigma \tan \phi
\]

Where:
- \( S \) = shear strength of the soil
- \( c \) = original cohesion of the soil
- \( \sigma \) = standard stress
- \( \phi \) = internal friction angle of the soil.

b. Root soil shear strength

The shear strength formula of undisturbed soil containing plant root distribution is:
\[ S = c + \sigma \tan \varphi = (c_o + \Delta c) + \sigma \tan \varphi \]

where:

- \( S \) - containing shear strength of root soil
- \( c \) - cohesive force containing root soil
- \( \sigma \) - standard stress
- \( \varphi \) - internal friction angle with root soil
- \( c_o \) - the original cohesion of the soil
- \( \Delta c \) - additional cohesion of the soil due to root action

However, the physical meaning of the shear strength index of the formula and the general soil is different. When the composite is subjected to shearing force, not only the friction between the soil particles and the soil particles is generated, but also the friction between the soil particles and the root system is generated. For the composite body, the internal friction is necessary. It is understood as the comprehensive friction angle of a composite of soil. The same \( c \) value includes not only the cohesive force between the soil particles and the soil particles, but also the cohesive force between the soil particles and the root system, and the root shearing resistance or anchoring force caused by the shear stress of the soil particles transmitted to the root system. When the anchoring force is greater than the root shearing resistance, the root shearing resistance is the main, and the anchoring force is the main one. Therefore, the \( C \) value can be understood as the sum of the cohesive force of the soil one-system complex and the root shearing resistance or anchoring force. The shear resistance or anchoring force of the root is an important component of the \( c \) value [6].

3.2. Analysis of factors affecting mechanical reinforcement of steep slopes by vegetation roots

The reinforcement effect of the root system on the steep slope soil layer is related to the distribution pattern of the root, the content of the root in the soil and the strength of the root.

a. Root distribution pattern

Roots grown on a plant can be divided into three types: lateral roots, vertical roots, and fibrous roots. The shape of the plant root determines its role in the stability of the slope, such as vertical roots and lateral roots play different roles. In general, the roots of the strong fibrous roots, which have a large vertical downward passage through the potential shear sliding surface, are more capable of improving the resistance to shallow landslides.

b. Content of roots in soil

The content of roots in soil is different, and the effect of roots on the reinforcement of soil is different, so the degree of influence of plants on slope stability is different. The roots are less and less in the soil as the depth increases. A commonly used measure of root content in soil is the “area ratio of roots” (abbreviated as RAR), which refers to the cross-sectional area of the root in a soil section (horizontal or vertical section). The ratio of the area.

c. Root strength

The strength of the roots of plants reported in various professional and technical literature varies greatly, mainly due to plant variety, growth environment, season, root diameter, root growth orientation and test methods (measuring the roots of air drying or wet) Root) and so on. However, a rule can be found from the data of the strength of many roots, that is: the strength of the root can reach 70 MPa, generally between 10 MPa and 40 MPa, and the strength of the root of the plant generally decreases as the diameter increases. The fine roots have a greater contribution to the improvement of the shear strength of the soil, because the fine roots not only have higher tensile strength, but also have a larger surface area than the coarse roots of the same RAR. The friction between the two is large and the ability to resist pull-out is strong.
4. Influence of vegetation root angle on the stability of the steep slope

As shown in Fig. 3, assuming that the slope angle is $\alpha$, the tensile force generated by one root OA of a vegetation on the slope surface is $F$, and the angle between the OA and the horizontal plane is $\beta$, the anti-sliding force generated by the root OA is $S$:

$$S = F \cos(\alpha - \beta) + F \sin(\alpha - \beta) \tan \varphi$$

where:
- $F$ - the tension generated for the root OA
- $\alpha$ - slope angle
- $\beta$ - the angle between the root OA and the horizontal plane (0° in the horizontal plane and positive in the counterclockwise direction).
- $S$ - anti-sliding force generated for root OA
- $\varphi$ - the internal friction angle of the rock and soil.

Unfolding the formula further, and the following is obtained:

$$S = F \left[ \cos \varphi \cdot \cos(\alpha - \beta) + \sin \varphi \cdot \sin(\alpha - \beta) \right] \cdot \frac{1}{\cos \varphi}$$

For a specific slope, $\alpha$ and $\varphi$ are known values. The safety factor of the surface sliding surface is:

$$K = \frac{W \cos \alpha \cdot \tan \varphi + \sum_{i=1}^{n} F_i \cdot [\cos \varphi \cdot \cos(\alpha - \beta)] \cdot \frac{1}{\cos \varphi} + CL}{W \sin \alpha}$$

$K$ - the safety factor of the surface sliding surface;
$W$ - Gravity (KN) of the surface sliding soil layer
$C$ - the cohesion (KPa) of the sliding surface soil (including the root system);
$L$ - Sliding surface length (m)

When $\varphi - (\alpha - \beta) = 0$, i.e. $\beta = \alpha - \varphi$, $S$ reaches the maximum.

$$S = \frac{F}{\cos \varphi}$$

Therefore, when the angle between the roots of the plant and the horizontal plane is $\alpha - \varphi$, the reinforcement effect on the soil layer on the surface of the rock mass is the greatest. At this time, the guest soil layer on the steep slope is relatively stable.

![Figure 3. Calculation diagram of root anti sliding force.](image)

5. Influence of vegetation on erosion resistance of steep slope

5.1. Rainfall erosion on steep slopes

At the beginning of rainfall, due to the large molecular force between the soil particles and the siphoning force of the capillary, and the surface is covered with cracks of different sizes, the rainwater
quickly penetrates into the ground, and the surface soil pores are quickly filled with water, and the water content first saturates. As the rainfall duration prolongs, the soil moisture continuously infiltrates under the action of molecular force and capillary siphon, and the saturated aquifer gradually thickens. In the process of absorbing water in the soil, when the rainfall intensity is greater than the rainwater infiltration strength, water is formed on the slope surface and flows to the slope foot under the action of gravity. The flow of water flowing on a slope is called slope runoff, which causes two erosions on the slope [7]:

a. Surface erosion

The runoff on the slope is in the form of a diffuse flow. The depth of the flowing water is small and the flow direction is often changed. Due to the raindrops splashing, the flow of water is disordered, and the direct shearing of the surface water is enhanced, and at the same time, the scattered soil particles become suspended and easily taken away by the water flow, so that the surface layer of the slope surface is denuded. When runoff is formed, the water depth and flow rate are proportional to the slope length during the rising slope runoff, and increase with the length of the slope and the duration of the rainfall.

b. Eclipse

Due to the roughness of the slope and the heterogeneity of the soil, as the rain continues to replenish, the flooding usually washes the slope out of many small grooves. The water flow in the small ditch must flow to the place with the least resistance, and the sandy soil containing more sand is easily eroded, but the handling is subject to the flow of water. Cohesive soils containing more powder or clay are more difficult to erode, but they are easy to handle, so the formed ditch is easy to store.

The development of the ditch is generally in the middle and lower part of the slope. Because the runoff and flow rate of the slope are increased, the erosive force is strengthened. Therefore, the more the ditch develops, the more severe the erosion will be, and the ditch will be wider and deeper. There are also many muddy sands.

The rainfall scouring induces the surface landslide of the rock slope by the following methods:
First, the surface soil of the slope, the rainfall infiltration and loading, that is, the water content of the ten bodies increases, the bulk density becomes larger, and the shearing strength increases. Second, the rainfall scouring changes the mechanical properties of the surface soil of the slope, resulting in a decrease in the cohesive force of the soil and a decrease in the shear resistance. In short, rainfall scouring mainly affects the stability of soil slope by increasing the weight of the soil and reducing the shear strength of the landslide body. Therefore, how to improve the shear strength of the soil is the key to the stability of the surface soil.

The splash of raindrops is an important form of raindrops on the erosion of steep slopes. Raindrops that fall at a certain speed during rainfall have a certain impact on the slope soil, and the soil particles are splashed and thrown off the ground, causing soil erosion. Ellison (1944), a foreign scholar, designed a "splashing board". Through rain experiments, it was found that raindrops can throw up fine soil particles up to 1.5m, and sand particles with a diameter of 4mm can also splash 20cm. The amount of mud sand splattered by a rain can be derived from the "splash plate" experiment. Place the test soil sample in a "splash plate" container and allow it to be splashed by raindrops. After a certain period of time, the dry weight difference of the soil sample before and after the splash is called, that is, the amount of raindrop splash.

Let the raindrop diameter be d, and hit the particle with D on the surface of the slope with speed. The momentum P is:

\[ P = m_r v_r = \frac{\pi d^3 \rho_r v_r}{6} \]

In the formula:
P - raindrop momentum
\( m_r \) - Raindrop quality
\( v_r \) - Raindrop speed
d - raindrop diameter

$\rho_w$ - Rain density

Assuming that the momentum component along the slope, all of it is transferred to the particle, and the component of the vertical slope is bounced back, that is, part of the component is passed to the particle. Assuming that this component is $k \cdot \frac{\pi d^4 \rho_w v_r}{6}$, $k < 1$, the particles will obtain a velocity and a velocity component off the surface of the slope, respectively, and the particles move down the slope with a horizontal distance of:

$$x = 2 \left( \frac{\rho_w}{\rho_s} \right)^2 \cdot \left( \frac{d}{D} \right)^2 \cdot \frac{6 v_r \sin \alpha \cos(1 + k)}{g}$$

In the formula:

$v_r$ - Raindrop speed
d - raindrop diameter

$\rho_w$ - Rain density

$\rho_s$ - particle density

$k$ - rain droplet momentum along the slope component ratio

When the particles leave the ground, they have a sub-speed down the slope $v_s$, then:

$$v_s = \frac{\rho_w}{\rho_s} \cdot \frac{d}{D} \cdot (1 + k) v_r \sin \alpha$$

If the raindrop is transmitted to the particle's component perpendicular to the slope, it is assumed that it is slipping downward after obtaining a certain initial velocity along the slope.

$$\Delta x = \left( \frac{\rho_w}{\rho_s} \right)^2 \cdot \left( \frac{d}{D} \right)^2 \cdot \frac{v_r^2 \sin^2 \alpha}{2g (\tan \phi - \tan \alpha)}$$

where:

$\phi$ - the angle of friction when the particles slide.

It can be seen from the above formula that the larger d, k, vr and $\alpha$, the farther the particle splashes; the smaller the D and $\phi$, the smaller the particle splashes.

5.2. Effect of vegetation on erosion resistance of steep slope

For rock slopes, the vegetation roots fix the passenger layer soil on the surface of the slope to reduce the erosion, thus slowing the water flow velocity on the slope and achieving the purpose of protecting the slope. Vegetation has unique and great effects on protecting water and soil and preventing shallow soil landslides in rock slopes, mainly in the following aspects:

a. Soil conservation

After the vegetation is used to reinforce the hillside, the roots of the vegetation are reticulated, the roots are tangled, and the vertical and horizontal connections are used to form a netting and pile-fixing effect on the soil structure, which increases the tensile strength and shear strength of the soil.

b. Transpiration

The transpiration of the vegetation allows them to extract water from the underlying soil, thereby reducing the water content of the soil. Its root system can be extended underground, distributed in soils with different water-containing conditions, and sucks out the deep and effective water seepage into the soil.

c. Water retainment

The role of vegetation in retaining rainwater and preventing erosion of topsoil is to protect the soil, avoid hits from raindrops, delay the fall of rainwater, and weaken the splashing force of raindrops. Different parts of the vegetation intercept a considerable amount of rainwater.
d. Changing soil hardness

The hardness of the soil determines the growth of the plant. In turn, the growth of the plant has a certain influence on the hardness of the soil. When the surface is weathered, the hardness of the topsoil becomes smaller. When the plant invades, the activity of the roots of the plant changes the surface soil hardness.

The steep water slope has poor water content and water holding capacity, and does not have the soil, water and nutrients needed for vegetation growth. Therefore, when vegetation restoration, engineering measures are usually taken to provide the conditions required for vegetation growth, such as laying a certain thickness on the slope. And it is better for the fertilizer and other soil. The guest soil layer needs to have sufficient cohesive force and anti-scour ability to closely cling to the rock slope to resist the erosion of rainfall. This adhesion and erosion resistance is largely determined by the coverage of the surface vegetation and the sparse distribution of the roots in the soil.

6. Conclusion

This paper discusses the effects of vegetation types, mechanical roots on the mechanical reinforcement of steep slopes, the stability of vegetation roots on the stability of steep slopes, and the influence of vegetation on the erosion resistance of steep slopes. The root system of simple herbaceous plants has a single distribution, and the effect of retaining the weathered soil layer is poor, and it is prone to decline, and the ability to survive is poor. The slope of the woody plant is stable and not easy to decline. The strength of the root of a plant generally decreases as the diameter increases, and the fine root has a higher tensile strength. When the angle between the roots of the plant and the horizontal plane is the \( \alpha - \varphi \), the reinforcement effect on the soil layer on the surface of the rock mass is the greatest. At this time, the guest soil layer on the steep slope is relatively stable. At the same time, vegetation can protect the soil, avoid the impact from raindrops, delay the rainwater landing, weaken the splashing force of the raindrops, and intercept a considerable amount of rainwater in different parts of the vegetation.

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