Three-dimensional geonet ecological slope protection technology and its engineering application

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Abstract: A protective structure system for slope with combination of vegetation and 3D geonet network was established. First the mechanism and ecological effects of slope protection with vegetation technology in slope engineering were discussed. Then specific implementation steps were proposed. Taking a slope ecological restoration project as an example, herbaceous plants suitable for slope protection were compared and tested, long term monitoring shows that the slope plants grow well, the protection effect of the new branches and roots were obvious, the stability of the slope was enhanced under comprehensive protection measures.

1. Introduction
More than 80% of the ground surface belongs to sloping land. In recent years, various projects in China have emerged to meet the needs of economic development. A large number of exposed slopes formed by engineering excavation, which damaged existing vegetation, caused a series of ecological and environmental problems such as soil erosion, landslides, and slope instability[1]. The traditional slope protection technology requires excavation and filling, which breaks the local ecological balance, and lacks landscaping and greening effects.

Slope ecological protection refers to measures to stabilize the slope using plants or plants combined civil engineering [2]. The slope ecological protection technology can not only meet the effects of reinforcement and treatment, but also can prevent soil erosion, purify the atmosphere, green and beautify the landscape, reduce noise, and absorb heavy metal pollution, etc. [1-4]. Three-dimensional geonet ecological slope protection is one of the slope ecological protection technologies. This technology has low cost, can effectively protect the slope from wind, rain, and flood erosion, and reinforce the slope. It is mostly used in actual engineering [5-6]. This paper introduces the three-dimensional geonet ecological slope protection technology and its engineering application, and provides theoretical and design basis for slope protection measures with vegetation.

2. Ecological slope protection theory

2.1 Basic idea
Three-dimensional vegetation geonet is a kind of yped seed planting material with three-dimensional structure, which can protect the ground surface being corroded before the turf is growing up, consolidate soil and fix the seeds. The compound protection layer formed after the grass grows up can prevent slope erosion.
2.2 Composite slope protection mechanism

The influence factors of vegetation on the slope system can be divided into three categories: mechanical effects, hydrological effects and biological effects \cite{7-10}. The 3D ecological geotechnical net combined vegetation can resist the tensile and shear stresses on the soil of slope, constrain the deformation of the soil, increase the cohesive force of the soil, and increase the lateral stress of the soil due to the restraint effect of the root. what’s more, plant growth activities can achieve the effect of root reinforcement, which can effectively improve the cohesion of nutrient soil and improve the integrity of the fragmented rock blocks on the slope, thereby increasing Anti-sliding force \cite{11} of rock or soil slope.

![Ecological slope protection stress circle](image1)

![Vegetation infinite slope model](image2)

2.3 Computing theory

The infinite slope model \cite{12} assumes that: ① the failure surface and the groundwater level surface are parallel to the slope surface; ② the failure surface extends indefinitely; ③ only one layer of soil is considered. When it is a multilayer, the shear strength and internal friction angle of the soil weighted average along the entire sliding surface. When considering the effect of vegetation reinforcement, the expression of safety factor is as follows:

\[
FS = \frac{C_r + C_s + \cos^2 \alpha [q_0 + \gamma(D \cdot D_w) + (\gamma_{sat} - \gamma_w)D_w] \tan \phi}{\sin \alpha \cos \alpha [q_0 + \gamma(D \cdot D_w) + \gamma_{sat}D_w]} \tag{1}
\]

Where: \( FS \) - safety factor; \( \alpha \) - slope angle; \( D \) - thickness of total soil; \( D_w \) - thickness of saturated soil; \( q_0 \) - vegetation load; \( C_r \) - soil cohesion; \( \varphi \) - effective internal friction angle; \( \gamma \) - natural soil weight; \( \gamma_{sat} \) - saturated soil weight; \( \gamma_w \) - water weight.

For selecting vegetation, the expressions of soil thickness and critical height of groundwater are as follows:

\[
d = \frac{C}{\cos \alpha} + \frac{(q_0 + \gamma_{sat} - \gamma_w - \gamma)D_w \cos \alpha \tan \phi}{\gamma \sin \alpha FS - \gamma \cos \alpha \tan \phi} \left[ q_0 + (\gamma_{sat} - \gamma)D_w \right] \sin \alpha FS \tag{2}
\]

\[
D_w = \frac{(q_0 + \gamma D)(\sin \alpha FS - \cos \alpha \tan \phi) - \frac{C}{\cos \alpha}}{\left( \gamma_{sat} - \gamma_w - \gamma \right) \cos \alpha \tan \phi - (\gamma_{sat} - \gamma) \sin \alpha FS} \tag{3}
\]

The infinite slope model is a two-dimensional model. If the failure surface is very narrow, the load-limit slope model is conservative.
3. implementation of geonet combined vegetation Slope Protection

(1) Slope Stability Analysis
The premise of the design of ecological slope protection is to meet the deep stability requirements.

(2) Slope cleaning and shaping
Trim the slope according to the designed shape. The landslide section is cut first, the slope is leveled and then filled with clay and tamped, and then reinforced with a bamboo grid in the shape of a square grid with a pitch of 1m.

(3) Design of slope interception and drainage system
Sidewalks are set up at a certain interval on the slope surface, with flow channels left on both sides, and stone drainage ditches at the bottom of the slope surface: excavation of interception ditch on slope sections with a slope height greater than 10m (about 100m), and the interception ditch is set inside the top edge. At 5m, the intercepting ditch adopts geomembrane composite mortar masonry structure. The construction of intercepting ditch follows the principle of vertical and horizontal, and it is completed continuously from top to bottom. Stepped energy dissipation sills are installed in the longitudinal drainage ditch.

(4) Excavation and backfilling of planting troughs
Excavate the planting troughs in a rectangular grid shape with a spacing of 1m in the horizontal direction and 2m in the vertical direction. Keep the grooves 20cm deep and 20cm wide. After slotting, backfill and compact the soil.

(5) Covered with nutrient soil
Prepare nutrient soil on site and cover the slope with 15cm thickness as base fertilizer.

(6) Laying three-dimensional geonet mat
A layer of geonet mat is laid in order from top to bottom and left to right on the slope covered with nutrient soil, and the net pad is closely attached to the slope. When fixing, the net pad must be smoothly combined with the slope and tightened. When laying the mesh pad on the top of the slope, it must extend 30 ~ 60cm. The geonet is laid in the fixed groove, and U-shaped nails are fixed at a distance of 1m, and the soil is backfilled and compacted.

(7) Cover soil
After laying the three-dimensional geonet, the cohesive soil, fertilizer, cement, etc. are mixed in a certain proportion and stirred uniformly, and then manually sprayed on the surface of the slope in 2 or 3 times.

(8) Yarrow grass seed spraying
According to the local natural, site, soil, climate and other conditions, select the appropriate vegetation type, and spray the mixed solution containing different herbs and shrub seeds, compound fertilizers, water retaining agents, adhesives, anti-transpiration agents, etc.

(9) Covered non-woven fabric
Sprinkle water evenly, then cover the mulch, make sure that the two mulches overlap 20cm, and fix it with a packing rope.

(10) Conservation
Regularly check the growth of plants and the humidity of the soil profile, and water, fertilize and spray as needed, and thinning, increasing seedlings, pruning or changing plant combinations according to the density of plant distribution.

(11) Construction is over
After passing the inspection, clear the field to ensure the surrounding environment is clean.

4. engineering practice

4.1 Project Overview
A river slope in the Yonghu area of Huizhou, Guangdong, as shown in Figure 3. Where belongs to the subtropical marine monsoon climate in South China. This slope was a cut slope of weathered rock residual soil. It was partially micro to moderate weathered rock and the slope was acidic. These
conditions were not conducive to the growth of plants. Without any vegetation cover, the soil erosion on the slope was serious.

Figure3 Pre-construction state of slope

4.2 Vegetation matching principle
The slope of this project has poor soil, high compactness, and poor management conditions. When selecting vegetation types, follow the corresponding principles \[13-14\]. Vegetation planting experiments were conducted for this project. As can be seen in the figure 4, ryegrass and trifolium were pioneer plants and were suitable for growth in winter. If the ratio of ryegrass and white trifolium was greater than 30\%, large-scale wilting and green-yellow disconnection will occur in summer. If it was less than 20\%, effective green vegetation cover would be difficult to form in winter, which easily cause soil erosion. The ratio of white trifolium, white happy grass, Bermuda and thrush is 1: 1: 4: 2: 2.

Figure4 Vegetation growth status chart.

4.3 Slope prevention and treatment effect
Because the slope was steep and there were too many shallow landslides, by using the 3D vegetation geonet, the sliding force of the local dangerous section can be spread to the stable section next to it, which can significantly improve the stability of the slope, and at the same time the role of soil retention and water retention wa helpful to the formation of vegetation ecological environment. The slope reinforcement design was shown in Figure 5, and the construction was shown in Figure 6.
In order to quantitatively analyze the function of the anchored geonet composite vegetation system, the bare slope at the same slope location and the slope after the ecological protection were selected for simulated rainfall erosion tests. The slope of the test section was 12m high and the slope angle was 65°. Transverse width 3m. The rainfall intensity is 2.5mm / min, the rainfall duration is 30min, and the speed of the raindrops landing on the ground is 9m/s. The erosion test results were shown in Fig. 7. The soil erosion on the bare slope without vegetation cover was more serious. The simulated soil erosion rate gradually increased before 19 minutes, and the soil erosion rate began to slow down after 19 minutes. Calculated up to 17kg, and soil erosion can not be seen on the slope protected by the anchored geonet composite vegetation. The long-term observations showed that the ecological slope protection effect is better, which can be seen from Figures 8 and 9.

![Figure 5: Ecological slope overall map.](image)

![Figure 6: Anchoring 3D geonet construction.](image)

![Figure 7: Relationship between soil loss and rainfall intensity.](image)
5. conclusion

The three-dimensional vegetation compound geonet can effectively protect the slope surface from rain erosion, slow down the impact of temperature changes, prevent and delay further weathering, fragmentation and erosion of the rock surface, and protect the overall stability of the slope. Survival and growth create a good water and fertilizer supply system to ensure the long-term growth of vegetation and achieve the purpose of long-term slope protection. Among them, the problems of artificial conservation, persistence of protection effects, and selection and configuration of plants need to be further improved in practical engineering applications.

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