Research on Key Technology of Near-Natural Slope Restoration Construction in Southern China

Huang XiaoZhong, Li JunFeng, Liu JunLong, Wan Cheng, Yang JingBo, Lin Jian, Xu Yifu, Feng Qi

Abstract— **With the continuous development of large-scale infrastructure construction for more than three decades, the issue of slope restoration in line with ecological protection is becoming more and more important. In this paper, from the perspective of slope structural loads, the research proposes quantitative analysis of the native vegetation characteristics to select plant species, as well as from the perspective of optimizing the scientific hydroseeding with adaptive maintenance to improve the slope structure and matrix bioactivity of the near-natural slope restoration construction technology. The practice of the three demonstration projects shows that this technology has the ability to carry out high-efficiency, near-natural, low-maintenance and long-term ecological benefits for the restoration of soil slopes, especially for the bare soil slopes, which can effectively save the cost of construction and maintenance of soil slopes, and has a good ecological and social benefits.**

Index Terms— **Composite matrix, near-natural, Slope body.**

I. Introduction

Over the past three decades, China's rapid infrastructure development and continuous construction expansion have significantly altered natural landscapes, resulting in a substantial reduction of secondary forested slopes with intact ecological communities and favorable environmental conditions[1-2]. This anthropogenic transformation has accelerated vegetation degradation and generated increasing areas of exposed earthen slopes, exacerbating soil erosion risks and ecological vulnerabilities. Concurrent with the evolution of ecological landscaping practices, there has been growing recognition and escalating demands for comprehensive slope restoration strategies encompassing geotechnical reinforcement, vegetation restoration, and ecological rehabilitation. The substantial environmental challenges have driven extensive implementation of earthen slope remediation projects nationwide, yielding numerous demonstration projects and empirical experiences. However, critical limitations persist in current restoration practices that require urgent attention[3-4].

The subtropical regions of South China exhibit rich native plant resources, offering diverse indigenous species suitable for slope revegetation. However, vegetation selection in restoration projects often demonstrates two scientifically unsound extremes: either indiscriminately pursuing rapid greening through monocultural plantations or excessively emphasizing aesthetic perfection with high-maintenance exotic species, both systematically neglecting the ecological suitability of native vegetation. These practices typically lead to emerging ecological complications several years post-restoration. Due to improper species combinations and insufficient competitive capacity among selected plants, stable ecological niches fail to establish, resulting in pervasive weed invasion[5]. Concurrently, vegetation degradation progressively occurs, ultimately causing partial slope re-exposure. These ecological regressions significantly diminish aesthetic value while substantially increasing long-term maintenance costs. Consequently, the restored slopes exhibit poor stability and unsustainable ecological performance, fundamentally undermining rehabilitation effectiveness.

Current research and technical understanding of slope restoration remain insufficient within the industry. Restoration efforts predominantly emphasize superficial revegetation while neglecting essential pre-rehabilitation structural optimization. This oversight results in multiple adverse consequences: inadequate improvement in post-restoration load-bearing capacity, insufficient stability of the vegetated slope foundation, and suboptimal community growth performance.

Slope revegetation methodologies are broadly categorized into transplantation and hydroseeding approaches. Transplantation techniques inherently face dual challenges. Firstly, root system damage during implementation creates entry points for pathogens, necessitating increased phytosanitary management costs. Secondly, the method's inherent inefficiency prolongs both construction and recovery phases, demanding excessive labor investment. While hydroseeding enhances operational efficiency, critical technical deficiencies persist due to insufficient theoretical guidance regarding species proportioning, fertilized seeding configurations, and bioactive matrix preparation. These shortcomings lead to unbalanced short-term and long-term nutrient supply, compromised substrate pathogen antagonism, and consequent ecological regression characterized by community degradation, diminished ecological efficacy, and unsustainable vegetation vigor.

In conclusion, earthen slope restoration requires continued advancement in two critical dimensions. First, vegetation selection necessitates quantitative analysis of native phytocommunity characteristics to determine optimal mixed seeding models and near-natural community configurations. Second, slope rehabilitation must prioritize structural optimization, matrix bioactivity with sustained fertility, and scientific hydroseeding coupled with adaptive maintenance protocols. Empirical validations confirm the technical maturity and significant efficacy of this methodology, which has been accredited as domestically advanced in slope

Manuscript received April 18, 2025
Huang XiaoZhong, Fuzhou Architectural Design Institute Co., Ltd
Li JunFeng, Fuzhou Architectural Design Institute Co., Ltd
Liu JunLong, Fuzhou Architectural Design Institute Co., Ltd
Wan Cheng, Fujian Boxing Stone Technology Development Co., Ltd
Yang JingBo, Fujian Boxing Stone Technology Development Co., Ltd
Lin Jian, Hunan Fifth Engineering Co., Ltd
Xu Yifu, China Construction Fifth Engineering Burean Co., Ltd
Feng Qi, Fujian Second Construction Group Co., Ltd

restoration engineering. To facilitate broader implementation, this systematic technique is formally codified as an engineered practice.

II. TECHNICAL PRINCIPLES AND CHARACTERISTICS

Technical Principle: The methodology involves quantitative field investigations to select native vegetation species in South China with high adaptability and competitiveness for slope restoration. Comparative multi-group experiments systematically validate the superiority of herb-woody-fertilizer mixed seeding patterns through germination potential, germination rate, and growth performance evaluations. Three optimized seeding configurations are established based on natural conditions to accommodate diverse slope gradients and aspects, providing theoretical guidance for efficient near-natural restoration.
Pre-restoration interventions employ structurally simple, stable, and cost-balanced slope reinforcement techniques to enhance load-bearing capacity. Hazard mitigation and slope optimization methods significantly improve slope stability, creating foundational conditions for sustained near-natural community establishment.
The protocol utilizes bioactive matrices combined with slow-release fertilizers to ensure long-term nutrient supply. Scientifically optimized spraying techniques enhance operational efficiency and application uniformity. Post-spraying adaptive maintenance, guided by vegetation growth dynamics and climatic conditions, ensures rapid revegetation and long-term ecological stability. The process has several characteristics:
(1) A comprehensive technical system integrating:
① Slope-adapted native species selection and near-natural community configuration
② Slope structure optimization methods
③ Bioactive slow-release spraying matrix development
(2) Quantitative analysis of native vegetation characteristics to determine optimal mixed seeding patterns and near-natural community ratios.
(3) Three rehabilitation priorities:
① Slope structural reinforcement and optimization
② Matrix bioactivity with sustained fertility
③ Scientific spraying techniques coupled with adaptive maintenance protocols

III. OPERATION POINTS

3.1 Seed Ratio Determination

The slope parameters including gradient, aspect, and soil layer thickness are measured. Based on three established community configuration reference tables, a seed ratio matching the slope characteristics is selected. Final adjustments are made according to local vegetation coverage patterns to determine the optimal seed mixture proportion.

(a)

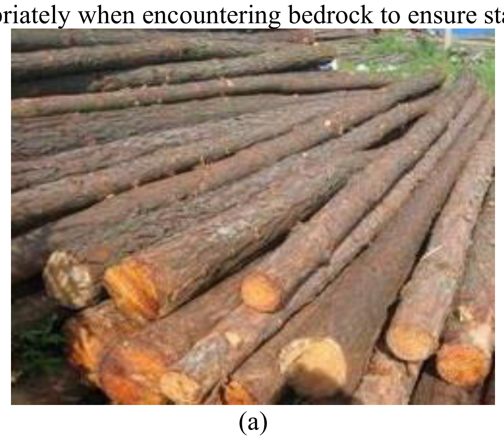
(b)

(c)

Figure.1 (a) Slope Gradient and Aspect Measurement; (b) Local Vegetation Characteristics Reference; (c)Final Seed Ratio Determination

3.2 Slope Body and Surface Optimization

(1) Timber Pile Construction: Vertically drive longitudinal timber piles (diameter: 6-25 cm, length: 2-5 m) at 0.5-3 m intervals in damaged slope areas. Reduce spacing appropriately when encountering bedrock to ensure stability.



(a)

(b)
Figure.2 Vertically Driven Pine Timber Piles (diameter: 6-25 cm) at 0.5m Intervals

(2) Clay Layer Construction: Fill and compact clay layers sequentially, achieving a soil compaction coefficient ≥0.93. Cover with nylon mesh, secure with transverse timber piles, and apply additional soil cover. Install horizontal timber piles (diameter: 6-25 cm, length: 2-5 m) above each longitudinal pile row. Increase transverse pile layers and quantities in thicker soil conditions.
(3) Slope Surface Preparation: Remove surface debris (isolated rocks, gravel, and waste) and excavate transverse shallow trenches (depth: 30 cm, width: 20 cm) from slope crest to toe at 20 cm intervals to enhance hydroseeding adhesion and erosion resistance.

Figure.3 Slope Surface Preparation Operations

Figure.4 Three-Dimensional Mesh Installation Effects

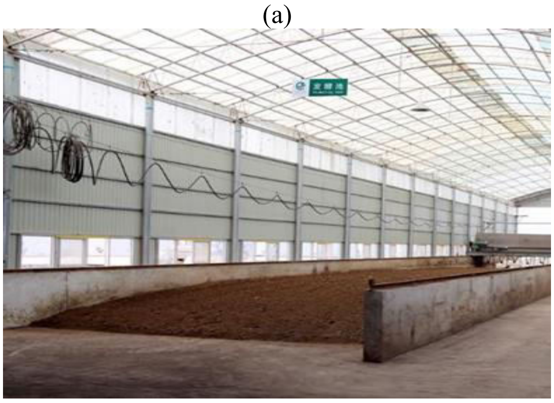
(4) Three-Dimensional Mesh Installation: Deploy the mesh with its textured surface facing upwards and smooth side contacting the slope. Extend the mesh 100 cm into interception ditches or soil, then lay it downward from the slope shoulder. Maintain 30 cm overlaps between adjacent mesh sheets, ensuring full contact with the slope surface without folds or voids. Fix the mesh progressively during installation, maintaining 5-10 cm overlap width.

3.3 Preparation of Long-Acting Bioactive Composite Matrix

(1) Organic-Inorganic Slow-Release Fertilizer Production
Fermented Organic Matter Preparation: Fermented organic matter serves as the base material. Step 1: Mix 60-75% cattle manure, 6-12% fly ash, 15-26% rice bran straw, and 1-6% yeast waste liquid. Initiate composting under controlled conditions: initial pH 5.5-8.5, C/N ratio 20-38:1, moisture content 40-50%, oxygen content 5-15%, and temperature 55-70°C with continuous aeration. Step 2: Add 1/1000-6/1000 rapid decomposer and complete fermentation within 6-13 days.
For granular organic fertilizer: Step 1: Blend 91-98% fermented organic matter with 1-8% borax and compost in storage silos at 35-50°C, turning the pile every 2-6 days until moisture content reaches 10-18%. Step 2: Grind the material to 50-210 mesh, then mix with 0.01-0.08% 10% diazinon granules and 0.1-1.5% kaolin. Pelletize via extrusion.
Final Fertilizer Formulation: Combine granular organic fertilizer, compound fertilizer (3.0-4.7 mm particles, N, P_2O_5, K_2O >30%), and coated fertilizer (3.0-4.7 mm particles containing 10% recycled thermoplastic resin-coated urea and 5% modified epoxy-coated diammonium phosphate) in a 1:1:3 ratio.

(2) Bioactive Matrix Production
Mix 55-75% herbal residue, 15-26% organic additives, 6-12% inorganic additives, and 0.4-3% microbial decomposer. Aerobic composting (pH 6-8.5, C/N ratio 20-35:1, organic content 45-60%) for 6-15 days yields the primary fermented product. Blend this with 2-6% maggot manure, 0.5-3% functional microbes, and 0.2-2% water-retaining agent. Conduct secondary fermentation in heated storage silos (floor temperature 35-50°C), turning every 2-6 days until moisture content reaches 10-18% (12-20 days). Sieve to retain particles ≤5.0 mm.

(a)



(b)
Figure.5 (a) Composite Material Composting Process; (b) Secondary Fermentation for Bioactive Matrix Preparation

3.4 Composite Hydroseeding and Adaptive Maintenance

(1) Hydroseeding Procedure

Figure.6 Matrix Homogenization and Mixing

Figure.7 Edge Test Spraying Operations

Seed Treatment: Soak seeds in 0.2% $KMnO_4$ solution for 10 min, followed by 8 h in clean water.
Mixing: Combine slow-release fertilizer, bioactive matrix, pulp, binder, and seeds.
Test Spraying: Perform trial sprays on marginal areas to achieve uniform slurry consistency (glossy but non-flowing).
Spray Application: Apply 3-4 layers vertically downward on slopes to achieve 3-4 cm thickness. Maintain 45-60° spray gun angles with overlapping passes, avoiding upwind operations.

Figure.8 Formal Hydroseeding Implementation

(2) Adaptive Maintenance Protocol
Immediate post-spray: Cover slopes with non-woven fabric or straw for 6-month moisture retention.
Week 1: Water twice daily.
Weeks 1-3: Water every 2 days, minimizing hydraulic impact.
Weeks 2-3: Monitor germination; remove covers when germination rate ≥70%.
Month 2: Thin seedlings based on growth uniformity.
Months 2-3: Gradually reduce irrigation frequency in thriving areas to enhance drought adaptation. Maintain targeted watering in underperforming zones or drought conditions.
Annual evaluation: Naturalistic community coverage typically exceeds 95% after 1 year of adaptive management.

Figure.9 Post-Spraying Slope Coverage and Maintenance

IV. CONCLUSION

4.1 Economic Benefits

(1) Reduction in Initial Construction Costs
The methodology prioritizes native species selection for earthen slopes and establishes three arbor-shrub-herb composite seeding models optimized for varying slope gradients and aspects. This standardized approach eliminates species screening redundancies, improving construction efficiency and achieving a 3.7% reduction in preliminary implementation costs.
(2) Mitigation of Mid-Term Remediation Expenses
Through timber pile configurations and drainage optimization, the slope reinforcement system enhances bearing capacity and erosion resistance. These technical improvements substantially reduce post-construction slope failure risks, yielding a 20.3% cost saving in slope remediation operations.
(3) Minimization of Long-Term Maintenance Expenditures
The integrated slow-release fertilizer and bioactive matrix system ensures sustained nutrient availability while suppressing phytopathogens. This dual mechanism supports stable community succession, effectively reducing recurring maintenance costs – including replanting, pruning, fertilization, and pest control – by 47.2% over conventional methods.

4.2 Social Benefits

The methodology integrates four core components: near-natural germplasm screening/formulation models, earthen slope structural optimization, bioactive matrix treatment for hydroseeding, and adaptive maintenance protocols. Validated through three demonstration projects, this system establishes a complete technical framework capable of delivering efficient, near-natural, low-maintenance slope restoration with sustained ecological benefits.
Amidst increasing demands for ecological rehabilitation of exposed earthen slopes, the methodology demonstrates dual advantages in cost reduction: minimizing both long-term maintenance expenditures and short-term construction investments for near-natural restoration. Through its growing adoption in domestic slope remediation practices, the technique contributes to:
(1) Advancement of slope restoration technologies

(2) Enhanced operational efficiency in slope rehabilitation
(3) Reduced lifecycle maintenance costs
(4) Improved post-restoration ecological performance
These systemic achievements in technical standardization, economic feasibility, and ecological sustainability substantiate the methodology's significant societal value for contemporary slope management challenges.

REFERENCES

[1] WEI S ,LI X ,WANG K , et al.Two decades of persistent greening in China despite 2023 climate extremes[J].Science China Earth Sciences,2025,68(04):1064-1073.

[2] Andrés P G ,Roberto J D ,Ignacio F I .Touristic urbanization and greening of coastal dune fields:A long-term assessment of a temperate sandy barrier of Argentina[J].Journal of Geographical Sciences,2025,35(01):206-230.

[3] Xin C ,Anning C ,Renjie G , et al.Variation of gross primary productivity dominated by leaf area index in significantly greening area[J].Journal of Geographical Sciences,2023,33(08):1747-1768.

[4] Liu L ,C.Seyler B ,Liu H , et al.Biogenic volatile organic compound emission patterns and secondary pollutant formation potentials of dominant greening trees in Chengdu,southwest China[J].Journal of Environmental Sciences,2022,114(04):179-193.

[5] Liu Y ,Zhang H ,Cui Y , et al.Distinct roles of alternative oxidase pathway during the greening process of etiolated algae[J].Science China(Life Sciences),2021,64(05):816-827.