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STATUS AND PROGRESS OF ENGINEERING RESEARCH ON SLOPE STABILIZATION OF LIVE TREE STUMP

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Abstract
The research status and achievements of live tree stump engineering technology at home and abroad are briefly summarized, and the representative achievements of live tree stump engineering technology in mechanics mechanism, calculation theory, engineering application status are briefly described and analyzed. Through the analysis, it is pointed out that live stump slope protection technology is a slope management technology that can better combine ecological and structural protection in ecological slope protection technology, but the current live stump slope protection technology still has problems such as inconsistent calculation theory, imperfect construction technology, and incomplete engineering application, etc. The research on the theory, construction technology and engineering practice of live stump slope protection technology should be strengthened.
Keywords: calculation theory; inconsistent calculation theory; imperfect construction technology

1 INTRODUCTION

In recent years, with the rapid development of China's economy and society, the domestic field of infrastructure construction has also been a good opportunity for development. However, the advancement of all kinds of infrastructure construction has also caused the destruction of the original ecological environment along the road sections, the construction of engineering construction has led to a large number of exposed slopes, making the original vegetation on the slope environment has been seriously damaged, at the same time making the native biological communities have been isolated and blocked, intensifying the deterioration of the ecological environment; infrastructure construction is also accompanied by a large area of slope excavation, leading to soil erosion in the engineering environment. In the end, the slope instability leads to landslide phenomenon, which threatens people's life and property, so slope management and research has become an unavoidable problem. The relevant researches of domestic and foreign scholars show that plant roots can effectively improve the shear resistance of soil, thus improving slope stability and facilitating slope reinforcement and landslide prevention.

However, due to the many influencing factors of plant slope fixation, the randomness of root distribution, the variability of root strength withplant species and the different construction methods of plant slope fixation, the mechanical mechanism of plant slope fixation is not fully understood and there is no unified standard for the quantitative evaluation of plant slope fixation.

Live tree stump slope stabilization engineering technology is a new type of soil slope protection technology, which has simple construction method, fast construction speed, low cost, and the reinforcing effect on the slope is not constant, but will be gradually enhanced with the growth and extension of tree roots. The technology has been widely used in developed countries due to its good economic and social benefits, and has also been applied in recent years in China in the management and protection of slopes.

This paper discusses the research status and progress of live tree pile technology at home and abroad, and provides theoretical basis and reference for further promotion of live wood pile technology.

2 MECHANICAL STUDY OF THE SLOPE STABILIZATION MECHANISM OF LIVE TREE STUMP

2.1 Concept of slope stabilization by live tree stump

After a period of maintenance, the stump will grow and develop in the soil. Before the development of the root system, the function of the stump is similar to anti-slip stump, and when the stump root system is completed, the stump root system will wind withthe slope soil to form a root-soil complex, when the stump root system plays a reinforcing role in the soil, it can effectively improve the shear strength of the soil, thus improving the stability of the slope soil, when the stump is buried deeper, the stump can also inhibit deep slope sliding.

2.2 Mechanism of live tree stump reinforcement

The reinforcement mechanism of live tree stump on the slope soil body is more complicated, and its influencing factors are numerous, but according to the summary of previous research, it is mainly reflected in the following aspects：

（1）The support of the stump itself: The tree trunk anchors in the soil of the slope play a role similar to that of an anti-slip pile, resisting the shear stresses generated by the landslide effect.

（2）Reinforcing effect of lateral roots of live tree stump on soil body: After maintenance, live tree stump will develop roots in the soil body to form a composite root system with the stump, and the lateral roots have obvious reinforcing effect on the soil body, which can convert the shear stress in the soil layer to the tensile stress of the root system, so as to improve the shear strength of the soil body.

（3）Live tree stump deadweight:The deadweight load of live tree stumps will increase the positive stress in the soil slope, thus indirectly increasing the shear strength of the soil.

（4）Plant transpiration: After the stump grows and develops, its leaves will produce transpiration and slow down the rainwater splash erosion, thus reducing the pore water pressure in the soil and improving the shear strength of the slope soil body.

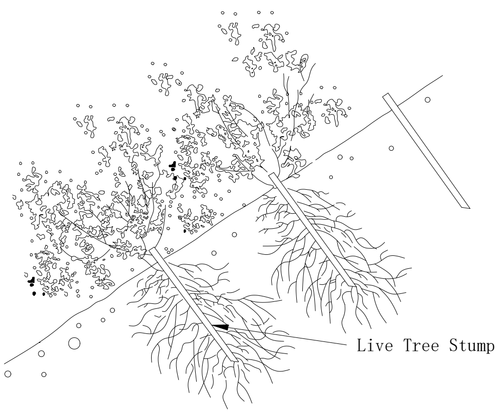

Fig.1 Sketch map of live tree stump

2.3 Mechanics of slope stabilization in live tree piles

The mechanical mechanism of slope fixation of live tree pile is more complicated, and many scholars at home and abroad have done a lot of research on the mechanical mechanism of slope fixation of plant roots, and have formed more perfect results. At the same time, the current research found that the mechanical action mechanism of live wood pile slope fixation can be roughly divided into two major aspects, one is the anchoring effect produced by the pile body, the other is the mechanical reinforcing effect produced by the fibrous roots after the growth and development of the pile body.

2.3.1 Anchoring theory

The theory of anchoring has been formed from the practice of geotechnical engineering since the 1960s, and the current engineering and theoretical circles are of the opinion that anchoring is concentrated in the following aspects [1]: suspension, combination beam, extrusion reinforcement, and the theory of strengthening the strength of the surrounding rock.

In their study, Danjon et al [2] regarded the main roots as "rods" that act as anchor rods in the soil and the fibrous roots near the main roots as ties that hold the main roots. The anchoring of the root system can be divided into three parts: the downhill fibrous roots mainly bear the soil compressive stress, the uphill fibrous roots mainly bear the soil tensile stress, and the vertical main roots are subjected to the soil shear stress. The slope-fixing effect of tree roots depends on the action of vertical roots and uphill fibrous roots, and their resistance to external forces depends on the material strength of the roots themselves, which is influenced by their material strength, soil strength and the bond strength of the root-soil complex. In their study, Longfeng and Chen [4] explained the anchoring effect of plant roots on the slope from the mechanical interaction mechanism between roots and slope, analyzed the influence of the mechanical characteristics of plant roots and root-soil complex interaction on the root anchoring effect, and provided reasonable and suggestions on the selection and configuration of plants on the slope. Shan Wei and Sun Yuying [5] verified the anchoring effect of deep roots of plants through field experiments on hagiotrophs, and concluded that deep roots of plants can significantly improve the shear strength of slope soil, and that the anchoring effect of roots will lead to the shear displacement of slopes with plant roots is significantly larger than that of plain soil slopes. He Jinnan [6] studied the anchoring properties of tree roots to soil and pointed out in his study that the presence of roots does play an anchoring role to the slope soil, but the geometric morphological structure of the root system and the type of slope soil will have a very important influence on the anchoring effect of roots. Zheng Li [7] studied the effect of root anchoring on slope stability and concluded that the safety factor of the slope is influenced by the length of the main root of the plant, which increases with the increase of the main root length. Zhang Chaobo [8] studied the relationship between the root diameter of oil pine and its tensile properties, and pointed out that there is a correspondence between the rootstock and the tensile strength of the root system, and it becomes a power function relationship, and the tensile strength, elongation and elastic modulus of the root system decrease correspondingly with the larger diameter. Wang Lixian [9] and Song Yun [10] believe that the thick and deep roots have greater stiffness, and when the soil around the root system has a sliding tendency, friction will be generated to hinder its sliding, at this time, the role of the root system is similar to an anchor, which can play the role of anti-slip pile and support wall to resist the shear stress produced by sliding soil body. Song Weifeng et al. [11] pointed out in their study that the anchoring effect produced by the vertical root system can be divided into three parts: 1) the hoop-bundle skeleton effect of the vertical root system on the root-soil complex; 2) the load-sharing effect of the vertical root system; 3) the stress transfer and diffusion effect of the vertical root system.

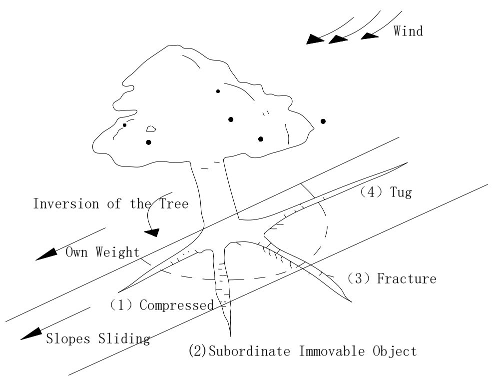

Fig.2 Anchorage mechanism of plant roots on slope

2.3.2 The theory of tendonization

The reinforced theory was proposed by the French engineer Henri-Vidal in the 1860s and successfully built the world's first modern reinforced retaining wall [12-13]. Subsequently, scholars at home and abroad have done a lot of theoretical research on the mechanism of reinforced soil action, and have formed a systematic mechanical theory of reinforced soil technology. Plant roots can be regarded as natural soil reinforcing materials, while root-soil complexes can be regarded as reinforced soils. The lateral root system formed after the development of live wood pile mainly plays the role of stiffening in the soil fixation effect, so the mechanism of stiffened soil has similarities with the soil fixation mechanism of the lateral roots of live wood pile.

At present, many scholars have done a lot of research on the reinforcement theory of the root system, and formed a more perfect theoretical results.Wu and Waldron [14-16] first proposed the mechanical calculation model of root system reinforced soil based on Moore-Cullen strength criterion, and Wu model proposed that the root-soil composite shear strength can be expressed in the form of cohesive force as follows ： $S = C + \sigma \tan\varphi + C_R$ .Contribution of root action strength to soil shear strength through C_R . The proposed Wu model provides a specific calculation method for the study of root-soil complex theory, and can be used to quantitatively evaluate the role of the root system under certain precision conditions for a specific root network. Wen Wei, Li Guangyuan et al [18], based on the Wu model introduced shear depth coefficient and the Wu model was modified and perfected, to get a new root-soil interaction stress sketch, to achieve vertical pressure, shear displacement, shear depth coefficient and root diameter on the description of the whole shear process. At the same time in its study to the short velvet grass root and salt ground fenugreek root protoplasmic root-soil composite for the study of the object to carry out shear tests and bring the test results into the modified model, through the calculation analysis shows that the modified model is closer to the test results than the Wu model, shows that the modified model is better than the Wu model in the reinforcement calculation. In the Wu model, the K value is often simplified to a constant, which is convenient for the prediction of plant stiffening, but a large number of experiments also show that the measured value of the root-soil composite shear strength is often lower than the calculated value, and the error is mainly due to the lack of rigor in the simplification of the K value, Xia Zhenyao. In their study, K values were analyzed in terms of the internal friction angle, the initial distribution angle and change of the root system on the shear surface, and the shear deformation angle when the root system was destroyed. Yuanzhan Wang and Xufei Liu [19] investigated the strength characteristics of in-situ and remodeled grass root stiffening soils by the indoor triaxial test method, analyzed the influence on the soil strength from the perspective of root content, and compared the strength differences between the two. The test results showed that when the root content of the remodeled soil reached 4-6 times that of the original soil, the damage strength of the remodeled soil and the original soil were basically similar. Wen Wei, Li Yanrong et al [22] conducted an experimental study on the stiffening effect of plant roots on soil under different peri-pressures, and dug up the root system of Dogtooth root in the field and randomly mixed it with red clay in Hainan to make a root-soil composite, and conducted a triaxial test on it under multiple peri-pressures. The shear strength index and reinforcement effect of the composite were analyzed and evaluated, and the test data indicated that there would be a big gap between the analysis using a large perimeter pressure and the actual situation in the field, while the shear strength of the root-soil composite using a small perimeter pressure in the triaxial test was more in line with the actual situation. Bu Zongju [23] studied the influence of horizontal and vertical root systems on slope stability, analyzed the shallow reinforcement effect of plant roots, and designed a slope stability calculation method that can take into account the soil anisotropy caused by the reinforcement effect of plants, which shows that different types of plants with different root systems should be planted at different locations of the slope to achieve the best ecological slope protection effect.

2.4 **Calculation method of slope stabilization for live tree stumps**

At present, there is no unified theory on the design and calculation of slope fixation of live tree stumps, but according to the mechanical mechanism of slope fixation of live tree stumps, there is a great similarity between the mechanism and that of forest tree roots. The theoretical basis of root system soil consolidation calculation of forest trees, at the same time the calculation and analysis of live tree stumps has great significance.

2.4.1 Theory of Main Root Anchorage Calculation

According to the related study [11], the vertical root system can be simplified as a full-length adhesive anchor with the main root as the axial axis and the lateral roots as branches to analyze the mechanical effect on the surrounding soil, and the anchoring force of the vertical root system can be calculated by adding up the friction between the root system and the surrounding soil.

For any root segment greater dl than $1mm$ at depth z below the surface, the root segment indicates a positive pressure of γ_z per unit area, where γ is the self-consuming weight of the soil. Make the coefficient of static friction between the root-soil is μ, so that the maximum static friction at this time is $\mu\gamma_z$, then the maximum static friction synergy force on the entire root segment is:

$$df_z = df \cdot \cos\theta = 2\pi r \cdot \mu\gamma_z \cdot dl \qquad (1)$$

In the formula.:

r – Root segment radius;

$A = 2\pi r \cdot dl$ – Surface area of the root segment;

The projected component of df in the direction of the plumbing is:

$$df_z = df \cdot \cos\theta = 2\pi r \cdot \mu\gamma_z \cdot dl \cdot \cos\theta = 2\pi r \cdot \mu\gamma_z \cdot dz \qquad (2)$$

From Equation 2, the component of the maximum static friction force in the direction of the lead hammer to which any root segment is subjected is independent of the angle of inclination of the root system θ.

For the entire root system, if the mean radius of the roots is such that the distribution function along depth z is $\overline{\gamma} = P(z)$, and the number of roots is such that the distribution function along depth z is $N = Q(z)$, then the component of the maximum static friction of the root system in the lead hammer direction in the subterranean $z - z + dz$ range is:

$$\sum dfz = N \cdot 2\pi\overline{r} \cdot \mu\gamma_z \cdot d_z = 2\pi\mu r \cdot P(z) \cdot Q(z) \cdot z \cdot dz \qquad (3)$$

Thus the integral can be given as:

$$F = \int_0^{\infty} \sum df_z = 2\pi\mu\gamma \int_0^{\infty} P(z) \cdot Q(z) \cdot zdz \qquad (4)$$

Therefore, the maximum anchoring force of the root system is:

$$T = F = 2\pi\mu\gamma \int_0^{\infty} P(z) \cdot Q(z) \cdot zdz \qquad (5)$$

Wherein, functions $P(z)$ and $Q(z)$ can be obtained by field measurements combined with data fitting. According to the above calculation theory, the maximum anchoring force of the vertical root system of the forest can be obtained

2.4.2 Root reinforcement calculation theory

There are two main types of views to reveal the mechanical change mechanism of root-soil complexes in the study of root reinforcement calculation theory, namely, frictional reinforcement theory [24-27] and quasi-adhesion theory. Two types of theories in the actual principle of action on the statement there are large differences, frictional tendon theory is essentially soil-root-soil interaction principle, that as long as the root strength is large enough and with the slope of the soil can produce enough resistance to maintain the stability of the root-soil complex. The quasi-cohesive force theory is essentially equivalent to the material principle [28-29], that the joint action of the root-soil complex is more complex, not only contains the shear force of the soil itself, but also contains the frictional resistance of the root system and the tensile force, their joint action makes the root-soil shear strength increase.

Wu.T.H. [14] established a root-soil interaction model on the basis of the relevant theories of material mechanics and soil mechanics according to Moore's Cullen's theorem, which can be used to evaluate the root reinforcement more accurately and quantitatively, and the model follows the following assumptions.

(1) The root system in the soil remains perpendicular to the shear surface.

(2) Root systems in the lower part of the shear surface can provide sufficient anchorage to ensure that plant roots are pulled out during the shearing process.

(3) Consider the root system as an elastomer, which is subjected to a pulling force that can be decomposed into forces acting in parallel and perpendicular shear planes.

(4) The model is based on Moore's Cullen's Theorem。

From the above assumptions, the root-soil interaction model can be derived as follows：

$$Sr = \Delta S + c + \sigma \tan\varphi = \frac{F_t}{A_s} + \frac{F_n}{A_n}\tan\varphi + c + \sigma\tan\varphi$$
$$= \frac{A_r T_N \sin\beta}{A_S} + \frac{A_r T_N s\cos\beta}{A_s}\tan\varphi + c + \sigma\tan\varphi \qquad (6)$$
$$= T_N(\sin\beta + \cos\beta)\frac{A_r}{A_s} + c + \sigma\tan\varphi$$

In the formula：

A_r ——Total cross-sectional area of roots；

A_S ——Shear area of the soil.

β ——Shear deflection angle of roots；

T_N ——Tensile strength of roots；

φ ——The internal friction angle of a prime soil.

Thus, the overall incremental shear strength of the root system against the soil is：

$$\Delta S = T_N(\sin\beta + \cos\beta\tan\varphi)\frac{A_r}{A_s} = \frac{T_N \delta A_r}{A_s}$$
$$= \sum T_i n_i(\sin\beta_i + \cos\beta_i\tan\varphi)\frac{a_i}{A_s} \qquad (7)$$
$$= 1.12\frac{\sum T_i n_i a_i}{A_s}$$

3 FINITE ELEMENT NUMERICAL SIMULATION STUDY OF LIVE TREE STUMPS

Xu Zhonghua and Tong Fengguang [30] conducted the first analysis of the effect of live stakes on slope stability using the finite element method and discussed the influence of the length, number, angle and root system development of live stakes on slope stability. The results show that live stakes can effectively improve slope stability, and the growing roots will greatly improve the safety factor of the slope; slope stability is positively correlated with the length and number of live stakes in the soil; there is a best reinforcing position of live stakes in the vicinity of 0.3 times the slope length from the foot of the slope; the best reinforcing effect is when the angle of the live stakes is 55o to the vertical direction. Song Weifeng, Chen Lihua [31] studied several key issues in the finite element numerical simulation of the interaction between tree roots and soil, and proposed that the growth and development of trees have obvious spatial and temporal characteristics, and the time-scale effects of the mechanical properties of the root-soil interaction should be considered in the finite element analysis, and that the finite element analysis of the root-soil fixation is based on the soil material parameters, root material parameters, and the time scale of the root-soil interaction. The final analysis is based on the friction parameters of the contact surface of the pile and the root soil, and the reasonableness of these parameters will affect the final analysis results. Wang Yun, Fu Wei et al. [32] designed a live wood pile skeleton vegetation slope protection structure, and used the finite element method to analyze the stability characteristics of the structure under different pile parameters and slope parameters, the analysis shows that the effect of live wood piles on slope protection is related to pile length, pile distance, pile diameter, and number of piles, in which pile length and pile distance have a significant influence on slope stability, while pile diameter and implantation angle have little influence. There is a certain positive correlation between the slope protection effect and the slope rate, and the technical parameters of the live wood pile slope protection structure are proposed based on the results of the finite element calculations. Hao Yuzhi, Zhao Jinyong et al. [33] analyzed the influence of pile position and pile length on slope stability by using ABAQUS finite element strength reduction analysis, and their calculation results showed that pile position has a great influence on slope stability, and improper pile position not only can not play a slope stabilization role, but also will reduce the stability of the slope. When the sliding surface is deeper and the pile body is shorter, it is difficult to extend the pile body to the sliding surface, and the anti-slip effect is better when the pile body is positioned at the slope body L=5/8.

4 ENGINEERING APPLICATIONS OF LIVE TREE STUMPS

The engineering applications of live wood piles are more common in developed countries in Europe and the United States, and the research and analysis of this engineering technology also started earlier, such as David F. Polster [34] and 1997 made a detailed introduction on the engineering applications of live wood piles on river bank slope stability, and proposed various forms of live wood pile application methods in his research, and also analyzed the application of various types of live wood piles in different projects. Application characteristics in the context.J.E. Norris [35] and others have discussed in detail the ecotechnical solutions for slope stability and erosion control. In their study, they proposed that live wood pile technology is widely used in the stability control of river slopes, mountain slopes, and road slopes, and is particularly common in the application of river slopes, and the form of live wood pile application is described in detail.Alex Duncan [36] applied live wood pile technology to a restoration project in the Austin, Texas, riparian zone in 2012, and the selection of plant species, the The depth of wood pile implantation was analyzed in detail. Its research proves that live wood pile technology is a low-cost and highly successful technique that can effectively replace traditional construction solutions.

In the domestic aspect, some scholars have also carried out engineering practice on the application of live tree piles, such as Xiaoping Li et al [37], in their research, used biological measures such as live tree piles and geotechnical gabions to repair the river bank slope of Shanghai airport. The erosion capacity, soil shear strength, and biodiversity were all significantly improved. Yue Junsheng [38] and others applied live stump engineering technology in the high grade highway soil slope from Yuping to Tongren, Guizhou Province, for the ecological protection of the slope, and their engineering practice results achieved remarkable results, which proved that the application of live stump technology in the highway soil slope is feasible, and at the same time, the live stump technology has obvious economic advantages, which opened up a new application pathway for the protection of the highway slope.

5 PROBLEMS

(1) At present, many scholars have more systematic research on the mechanics of soil fixation mechanism of tree roots, and the mechanics of slope fixation mechanism of tree roots and live wood pile has greater similarity, has greater reference significance, but the relevant research on the mechanics of live wood pile is still to be solved.

(2) The design and calculation method of live wood pile slope fixation can draw on the anchoring theory and reinforcement theory for analysis, but still lack of relevant unified theoretical guidance, which greatly restricts the promotion of live wood pile slope fixation technology.

(3) The numerical simulation study of live wood pile is mostly concentrated on the study of single pile or single row of piles, lacking the analysis and study of group pile effect.

(4) The practical application of live wood pile slope fixing engineering technology is mainly concentrated on the protection and management of river bank slopes, and less on the application of highway slopes and other types of slopes.

(5) The construction method of live wood pile slope fixing engineering technology is lack of relevant research, no unified construction process.

(6) There is no relevant experimental analysis of live wood pile slope fixing engineering technology, and there is a lack of research on relevant test methods and test equipment.

6 DEVELOPMENT TREND

Live tree pile slope stabilization engineering technology has the advantages of convenient construction, low cost, fast construction speed, good slope protection effect, etc., and live wood pile can refer to the design theory of friction pile and anti-skid pile in the design calculation stage, which has the possibility of reliable quantitative analysis, and has a larger development prospect in the future slope protection project. However, most of the current research focuses on the numerical simulation of finite element and engineering application research, and there is not enough research on the mechanical mechanism, design calculation theory, group pile effect, integrated effect of live wood pile and vegetation, and construction process of live wood pile. Therefore, the future development direction of live wood pile slope stabilization engineering technology is as follows.

(1) Since the slope stabilization theoretical calculation of live tree piles is based on the root-soil mechanical mechanism, it is necessary to further study the mechanical mechanism of live tree piles on the basis of the research on the root-soil stabilization mechanical mechanism of forest trees, and propose the mechanical mechanism model of live tree piles.

(2) Based on the calculation theory of friction pile and anti-slip pile, the design calculation theory of single pile of live wood pile should be studied in depth, and the relevant calculation model should be proposed, and the relevant calculation expressions should be deduced.

(3) In-depth study on the influence of group pile effect on slope stability, quantitatively analyze the

influence law of pile length, pile distance, pile number and pile position on the change of slope safety factor, and propose relevant calculation theory.

(4) Live wood piles can effectively prevent landslides on shallow slopes, so in the future it is necessary to deeply study the influence of live wood piles on the potential sliding surface of slopes, and explore the influence law of the inhibitory effect of live wood piles on the potential sliding surface of slopes.

(5) In-depth research on the test method and test equipment for the slope stabilization effect of live wood piles, and demonstrate and analyze the influence of live wood piles on slope stability from an experimental point of view.

(6) The construction process of live wood pile slope stabilization engineering technology is of great significance to its popularization, so in the future we need to do in-depth research on the construction process of live wood pile and propose a unified construction process.

Summing up the above analysis, we can conclude that live wood pile slope fixing engineering technology is a new slope fixing technology with great application prospect, combining structural protection theory and ecological protection method. However, due to the lack of research at this stage, the promotion of the technology is relatively slow, although this paper makes a certain outlook for its future development, but the theoretical research on how to carry out the live wood pile technology remains to be further explored.

Acknowledgments

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REFERENCES

[1] Yan Mo Ming, Xu Zhenxiang, Su Ziyao, Editor-in-chief. Handbook of Geotechnical Anchorage [M]. Beijing: People's Transport Press, 2004 .

[2] Danjon F,Fourcaud T,Bert D.Root architectu re and wind-firmness of mature Pinus pina ster[J].New Phytolog-ist,2005,168(2) :387－400.

[3] Crook M J,Ennos A R.The anchorage mechanics of deep rooted larch,Larix europea X L.japonica[J].Journal of Experimental Botany,1996,47(10) : 1509-1517.

[4] LONG Feng, CHEN Jianrong, SUN Hailong. Root system anchoring based slope protection planting[J]. Roadbed Engineering,2009(02):13-14.

[5] Shan Wei, Sun Yuying, Wang Qiang, Hao Juying. Slope protection mechanism and deep-root anchorage of high grade highway slope plants[J]. Journal of Northeast Forestry University, 2008, 36(11):59-60+63.

[6] JI Jinnan. Research on root anchorage based on root-soil interaction mechanism[D]. Beijing Forestry University, 2007.

[7] Zheng Li. Effect of plant root stiffening and anchoring on slope stability [D]. Southwest University,2018.

[8] Zhang Chaobo. Fundamental research on the mechanics of forest tree root system for soil stabilization and slope protection[D]. Beijing Forestry University,2011.

[9] Wang Lixian. Soil and water conservation [M] Beijing: China Forestry Press, 2005, 243-244.

[10] Song Yun. Mechanisms of slope stabilization by plant soil fixation[J]. Forest Engineering,2004,20(5) : 51-52.

[11] Song Weifeng, Chen Lihua, Liu Xiuping. Theoretical basis of root system soil fixation in forest trees [J]. Soil and Water Conservation Bulletin, 2008, 28(6):180-186.

[12] Luo Xingchun, Fan Jiacheng. Mechanical principles and yield conditions of reinforced soils[J] . Journal of Yunnan University of Technology, 1996 , 12(2):14 -18 .

[13] Ouyang Zhongchun . Modern Geotechnical Reinforcement Technology [M]. Beijing :People's Transport Press, 1991.

[14] Wu T H,Mckinnell W P,Swanston D N.Stre ngth of tr-ee roots and land-slides on Princ e Of Wales Island［J］.Alaska Can, Geotec h.J.1979(16):19-33.

[15] Waldron L J,Dakessian S.Soil reinforcement by roots:calculation of increased soil shear resistance from roo-t properties[J].Soil Sci ence,1981,132:427-435.

[16] Wu T H.Investigation on Landslides on Prin ce of Wa-les Island[R].Dpt Civ Eng,Ohio State Univ Columbus,USA,1976.

[17] Wen Wei, Li Guangfan, Hu Wei, Liu Huij iang, Xiang Wen. Modification of the mod el for the stiffening effect of herbaceous pl ant roots on soil [J]. Journal of Rock Mec hanics and Engineering, 2016,35(S2):4211-4 217

[18] XIA Zhenyao, XU Wennian, TAN Yunzhi, CHEN Fangqing. Analysis of the contributi on coefficient of root stiffening for the cla

ssical model of root system soil consolidation[J]. Journal of Hydrology, 2014,45(S2):61-66.
[19] WANG Yuanzhan, LIU Xufei, ZHANG Zhikai, MA Dianguang, CUI Yanqiang. Experimental study on the effect of root content on the strength of in-situ and reshaped grass root reinforced soils[J]. Journal of Geotechnical Engineering,2015,37(08):1405-1410.
[20] CHEN Changfu, LIU Huaixing, LI Yaping. Indoor triaxial test study of grass root reinforced soil[J]. Geotechnics,2007,28(10):2041-2045..
[21] Hu Qizhi, Zhou Zheng, Xiao Benlin, et al. Experimental study on the relationship between soil root content and shear strength in ecological slope protection[J]. Geotechnol. 2010, 24(5):85-87.
[22] WEN Wei, LI Yanrong, LI Guangfan, HU Wei, LI Tie, LIU Huijiang, Xiang Wen. Experimental study on the effect of herbaceous roots on soil stiffening under different perimeter pressures[J]. Quarterly Journal of Mechanics,2016,37(01):124-130.
[23] Bu Zongju. Effect of shallow stiffening action of vegetation root system on slope stability[J]. Journal of Beijing Jiaotong University,2016,40(03):55-60.
[24] Sun Lida, Zhu Jinzhao. The comprehensive benefits of soil and water conservation forest system [M]. Beijing: China Science and Technology Press, 1995.
[25] YANG Guolin, WANG Yonghe. Tensile test study of reinforced soil reinforcing materials [J]. Journal of Coal, 2000, 25(1):51 -54
[26] Yang Golin. Structural Stability Analysis and Engineering Application of Mesh Reinforced Soil Retaining Structures [J] . Journal of Coal, 1999 , 24(1):78 -81 .
[27] Wu Jinghai, Wang Dequn, Chen Huan. Experimental study on the triaxial test of reinforced sand soil of geosynthetic materials[J] . Journal of Geotechnical Engineering, 2000 , 22(2):199-204 .
[28] Bai Xiaohong, Huang Xianzhi, Zhang Wei. Application of Reinforced Soil Technology in Civil Engineering Use [J] . Journal of Taiyuan University of Technology, 2003, 34(5):532-5344.
[29] Jie Yuxin, Li Guangxin. Finite Element Calculation of Fiber Reinforced Soils [C], The Sixth National Symposium on Numerical Analysis and Analytical Methods for Geotechnical Properties. Guangzhou:1998 :309 -314.
[30] Xu Zhonghua, Chen Jinjian, Wang Jianhua, Feng Jincai. Numerical analysis of the effect of live tree pile slope stabilization on slope stability[J]. Geotechnics, 2004(S2):275-279.
[31] Song Weifeng, Chen Lihua, Liu Xiuping. Key issues in the finite element numerical simulation of the interaction between tree roots and soil[J]. Soil and Water Conservation Research,2009,16(04):6-13.
[32] Wang Yun, Fu Wei, Wu Wanping, He Bin, Ruan Yanbin. Structural design and parameter optimization of ecological slope protection by live wood piles[J]. Highway,2015,60(06):228-234.
[33] Hao Yuzhi, Zhao Jinyong, Lu Ming, Peng Wenqi, Wang Qi. Effect of live wood pile position and pile length on bank slope stability[J]. People's Zhujiang River, 2019,40(01):102-108.
[34] David F. Polster. Restoration of landslides and unstable slopes:considerations for bioengineering in interior l-ocations[C].Proceedings of the 21st Annual British C-olumbia Mine Reclamation Symposium in Cranbrook, BC, 1997.
[35] J.E. Norris.Slope Stability and Erosion Control:Ecotechnological Solutions[M]. The Netherlands Published by Springer,2008.
[36] A Duncan,J Klingshirn.Live Staking in Austin, Texas Riparian Zone Restoration Projects SR-12-15, October 2012[R].City of Austin Watershed Protection,USA,2012.
[37] Xiaoping Li,Liquan Zhang,Zheng Zhang.Soil bioengineering and the ecological restoration of riverbanks at the Airport Town,Shanghai,China[J].Ecological engineeri-ng,2006,26(3):304-314.
[38] Yue Junsheng, Li Hui, Chen Ke-qun, Shen Yiping. Application of live wood pile soil consolidation and grass planting technology in highway soil slope protection[J]. Highway Traffic Science and Technology (Applied Technology Edition), 2009,5(10):174-176.