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Experimental Study on Mechanical Properties of Plant Roots in Rocky Desertification Ecological Restoration Area of Yunnan Province

Bin Xu[1,a,*], Yong Yang[1,b]

[1]*Faculty of Architectural Engineering, Kunming University, Kunming, Yunnan, China*
[a]2363282036@qq.com, [b]958101044@qq.com
[*]Corresponding author

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Abstract: Soil and water loss is serious in rocky desertification areas. To explore the soil-enhancing effect of the root system of Indigofera amblyantha Craib, root-soil complexes with root-soil cross-section ratios of 0.10%, 0.24%, 0.42%, and 0.65% were prepared for conducting direct shear tests to obtain the shear strength and establish the relationship between the root-soil cross-section ratio and the shear strength. The results show that plant roots increase the shear strength of the soil. As the root-soil cross-section ratio increases, the soil shear strength increases, but there is an optimal root-soil cross-section ratio. The research results provide a theoretical basis for ecological restoration in rocky desertification areas.

1. Introduction

Rocky desertification is very severe in China, which is mainly concentrated in eight provinces and cities in southwest China such as Guizhou, Yunnan, and Guangxi. As many as 220 million people are affected by rocky desertification. Rocky desertification accelerates the deterioration of the ecological environment, devours the living space of human beings, and leads to frequent natural disasters, which has seriously affected regional economic development and endangered the ecological security of densely populated areas such as the Yangtze River and Pearl River Basins in south China [1]. The party and the central government have always paid great attention to the issue of rocky desertification. In November 2012, the report to the 18th National Congress of the Communist Party of China included the construction of ecological civilization into the "five-in-one" overall layout of the cause of socialism with Chinese characteristics, and clearly proposed to promote comprehensive governance of rocky desertification. In January 2016, General Secretary top leaders of China clearly stated at the symposium on promoting the development of the Yangtze River Economic Belt that the rocky desertification governance project must be properly implemented. Therefore, enhancing the governance of rocky desertification has become an ecological issue that has attracted widespread attention from the whole society and great importance from the government, and has been a very important part of the government's work since the 18th

National Congress of the Communist Party of China.

2. Current Research Status at Home and Abroad

Comprehensive governance of rocky desertification plays an important role and is of great significance in economic and social development, ecological civilization construction, and targeted poverty alleviation [2]. It has become the main policy trend of the current competent authorities at all levels, and has become a focus of attention in China's governments, academic circles, and society. Besides, the central government has invested a lot of money in the governance of rocky desertification, and the intensity of governance has increased year by year. Overall, great achievements have been made in the prevention and control of rocky desertification, a large amount of successful experience in the governance of rocky desertification has been accumulated, and a number of relatively mature comprehensive governance models and technical systems for rocky desertification have been formed. Rock desertification prevention and control technologies can basically be divided into two categories, namely direct and indirect ones [3].Direct prevention and control technologies include biological governance technology, which is mainly aimed at restoring vegetation in rocky desertification areas and has been constantly developed to form a technology system [4]. Through vegetation restoration in rocky desertification areas, plant roots hold the soil and have the effect of entangling and consolidating the soil, which can slow down the occurrence of disasters such as soil and water loss. Besides, the plant root system is mainly composed of protein, sugar, and fat, similar to polymer materials. The cell wall of the root system is composed of an extensin network and a cellulose microfibril network intertwined with each other, which has certain tensile properties, so the root system can be regarded as reinforcement materials, Yang Yachuan et al. [5] believed that plant roots have an obvious "reinforcing effect" on the soil, and first proposed the concept of "soil-root complex", which provided new ideas for subsequent research. For this complex material, researchers have conducted relevant studies from different perspectives. In terms of the number of plant roots, plant roots can form a root network with soil particles to firmly fix the plant body in the soil, which is equivalent to having a certain reinforcing effect on the soil. In view of this reinforcing effect, Mao Xurui [6], Jiang Xiyan [7], Luo Luyao [8], and Sun Qingmin [9] studied the shear strength of soil with different average root content through direct shear tests, and pointed out that as the root content increased, the cohesion of the soil increased, the cohesion of soil mass increased, the shear strength increased, and the cohesion of the root-soil complex increased to varying degrees compared with the root-free soil. The cohesion and the cohesion growth rate were positively correlated with the root-soil area ratio and root-soil volume ratio [10]. Through direct shear tests, it was found that when the applied normal stress was small, the plant roots added to the soil basically bore all the shear stress during the shear process. At this time, the shear stress became smaller with the increase of shear strain, which made the stress-strain curve relatively gentle, that is, the shear strength of the root-soil complex was not linearly related to the number of roots. It showed that as the root area ratio increased, the shear strength of the root-soil complex showed a trend of increasing first and then decreasing, that is, there is optimal root content [11]. When the root content was higher than the optimal dosage, the interaction between roots and soil was weakened, and the cohesion and internal friction angle of the root-soil complex decreased instead of increasing, and the shear strength also decreased [12]. In terms of the form of root distribution, many scholars placed roots evenly in the soil and conducted experimental research on the shear strength of the root-soil complex. Shi Haoting et al. [13] pointed out that when all root systems were perpendicular to the shear plane, the more concentrated the root distribution was, the more obvious the improvement in the shear strength of the root-soil complex. Regarding how the root distribution method of plant roots affects the shear strength of soil, Kong Gangqiang et al. [14] compared the root enhancement effects of different distribution forms such as horizontal, vertical, inclined, intersecting, and mixed, and pointed out that the enhancing effect of the root system was the most obvious under the mixed distribution form, with root system enhancement effect coefficients of about 1.4 to 1.5. The above studies believe that due to the existence of plant roots, the cohesion of the soil increases, but have little impact on the internal friction angle of the soil [15]. These research conclusions are helpful for people to quantify the soil-fixing efficiency of roots. However, the above studies are basically based on soils whose soil fertility has not declined. In rocky desertification areas, the soil layer is thin, the soil volume is small, the gravel content is high, the fertility is poor, the permeability is strong, and the distribution is scattered, coupled with large mountain slopes and poor ability to intercept and retain precipitation [16], all of these make vegetation restoration in rocky desertification areas faces many difficulties. Therefore, it is of great significance to study the soil-fixing ability of plant roots in rocky desertification areas.

3. Analysis of Soil-Fixing Performance of Plant Roots in Rocky Desertification Areas

3.1. Indoor Shear Test

When geological disasters such as landslides, collapses, debris flows, etc. occur on soil slopes, the soil is sheared instantly and the drainage phenomenon is not obvious, so the shear test is conducted using the quick shear method. In the test, Indigofera amblyantha Craib, which is common in rocky desertification areas, was selected to study the shear strength of the root-soil complex. The prepared root-soil complex and plain soil samples were placed on a strain-controlled direct shear instrument (Fig. 1) and shear tests were conducted according to the method in the literature [17].Figure 1 direct shear instrument.

Figure 1: Direct shear apparatus.

3.2. Shear Test Results

This test focuses on testing the effect of adding different cross-sectional areas of the Indigofera amblyantha Craib root system to the soil on the shear strength of the soil. The cross-section size of the ring cutter used in the direct shear test of the root-soil complex is 61.8 mm in inner diameter. An Indigofera amblyantha Craib root system with a root diameter of 2 mm-5 mm was placed in the middle of the ring cutter. After adding plant roots, the ratio of the cross-sectional area of plant roots to the cross-sectional area of the ring cutter is the root-soil cross-sectional ratio, and the specific root-soil cross-section ratio is shown in Table 1.

Table 1: Root-soil cross-section ratio

Added plant root diameter	2	3	4	5
Root-soil cross-section ratio	0.10%	0.24%	0.42%	0.65%

The test results are shown in Table 2.

Table 2: Soil shear strength under different root diameters

Plant name	Root-to-soil cross-section ratio	Shear strength		
		Test value(kPa)	Increment(kPa)	Relative increment (%)
Pure soil	0	20.83		
Indigofera amblyantha Craib	0.10%	22.71	1.88	9.03
	0.24%	24.25	3.42	16.42
	0.42%	27.24	6.41	30.77
	0.65%	24.53	3.70	17.76

It can be seen from the test that the internal friction angle of pure soil is 20.83 kPa. After adding plant roots, the shear strength of the soil changes in the range of 22.71 kPa ~27.24 kPa. The histogram of root-soil cross-section ratio and shear strength is shown in Figure 2. It can be seen from Figure 2 that adding plant roots increases the shear strength of the soil. However, when a certain root-soil cross-section ratio is reached, the shear strength of the soil will decrease accordingly, and there is an optimal root-soil cross-section ratio.

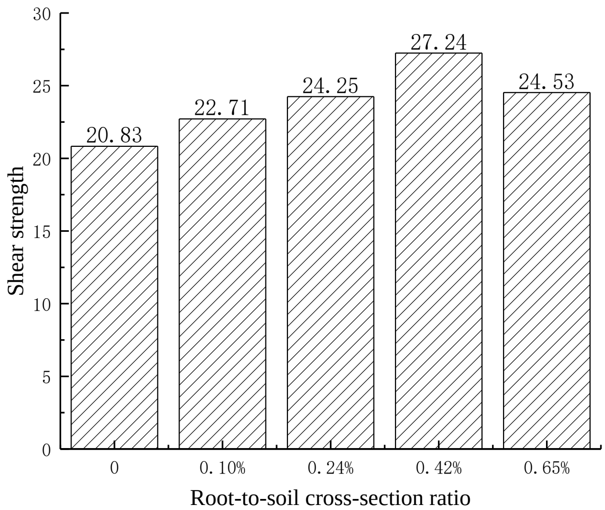

Figure 2: Histogram of root-soil cross-section ratio and shear strength.

According to the data in Table 2, the equation fitting the relationship between root-soil cross-section ratio and shear strength is

$$y = 20.49 + 26.67x^2 - 30.82x^2 \quad (1)$$

Where y represents the shear strength and x represents the root-soil cross-section ratio. According to the data in Table 2 and the fitting formula, the relationship curve between the root-soil cross-section ratio and shear strength can be drawn after adding the number of plant roots (Figure 3).

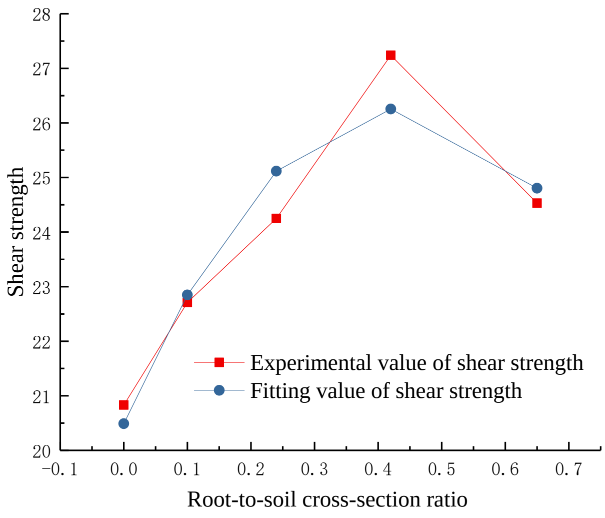

Figure 3: Relationship curve between root-soil section ratio and shear strength.

4. Conclusions

The root system of Indigofera amblyantha Craib is roughly cylindrical, and the surface of the root system is rough and uneven. These uneven parts improve the engagement between the plant roots and the soil and enhance the shear strength of the soil. However, the test results show that the shear strength of the root-soil complex is not linearly related to the root-soil cross-section ratio, but there is an optimal root-soil cross-section ratio. This is because fine roots can bond well with the soil. However, as the root diameter increases, although there is a larger contact area between the roots and the soil, which further increases the friction, the roots become thicker and the roots are easy to loosen in the soil and difficult to slide as a whole with the soil. When shear failure occurs, the root system is easy to slide and does not fully play its role in resisting damage. The root system of Indigofera amblyantha Craib also has certain tensile properties. During the shearing process of the root-soil complex, it is not easily broken when stressed. It is similar to adding "rebar" to the soil, which strengthens the performance of the soil.

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References

[1] He Xiaojia, Wang Lei, Ke Bing, Yue Yuemin, Wang Kelin, Cao Jianhua and Xiong Kangning.(2019) Progress on Ecological Conservation and Restoration for China Karst. Acta Ecologica Sinica, 18, 6577-6585.

[2] Zuo Taian, Zhang Fengtai, Yu Shijie, Li Jiao, Fan Hao and Ye Dan.(2022) A Sudy on Poverty Caused by Rocky Desertification in Karst Areas of China. Carsologica Sinica, 6, 915-927.

[3] Ke Qihua, Zhang Keli, Wang Aijuan, He Jianghu and Zhang Siqi.(2021) Database Construction and Multi-scale Integrated Arrangement of Eco-technology for Combating Karst Rocky Desertification. Bulletin of soil and water conservation, 6, 237-248.

[4] Yuan Chengjun, Xiong Kangning, Rong Li and Weng Yinfang.(2021) Research Progress on the Biodiversity During the Ecological Restoration of Karst Rocky Desertification. Earth and Environment, 3, 336-345.

[5] Yang Yachuan, Mo Yongjing, Wang Zhifang, Liao Zhixi, Deng Jian and Zhang Xinping.(1996) Experimental Study on Anti-Water Erosion and Shear Strength of Soil-Root Composite. Journal of China Agricultural University, 2, 31-38.

[6] Mao Xurui, Xu Penghai, Cao Yue'e, Fan Mengcheng and Yang Jianjun.(2019) Experimental Study on Shear Strength of Plant Roots in Open-pit Coal Mine Wastelands. Science of Soil and Water Conservation, 6, 103-110.
[7] Jiang Xiyan, He Chunxiao, Zhou Zhanxue ang Guo Yangyang.(2019) Effect of Root System on Shear Strength of Soil in Ecological Slope Protection. SWCC, 3, 43-46+69.
[8] Luo Luyao, Song Lu, Zhu Haili, Li Benfeng, Zhang Ke, Liu Yabin, Li Guorong and Zhang Yu.(2020) Influence of Root Paramenters to the Shear Resistance of Soil-Root Composite. YELLOW RIVER, 10, 42-46.
[9] Sun Qingmin, Ge Yonggang, Chen Pan, Liang Xinyue and Du Yuchen.(2022) Evaluation of Factors Affecting the Shear Strength of Root-soil Composite of Typical Plants in Wenchuan County. Journal of soil and water conservation, 1, 58-65.
[10] Xue Hailong, Tang Biao, Zhang Jingyuan, Shen Yanhui, Xu Jianxin and Wang Ying.(2019) Effects of Hypericum Per foratum Roots on Shear Strength of Slope Soil. Bulletin of soil and water conservation, 3, 87-92.
[11] Liao Bo, Liu Jianping and Zhou Huayu.(2021) Effects of the Influence of Root Content on the Shear Strength of Root-soil Composite of Bischofia javanica. Journal of soil and water conservation, 3, 104-110+118.
[12] Ma Qiang, Li Zhi, Xiao Henglin and Wan Juan.(2020) A Simplified Calculation Method for Shear Strength of Tap Root-Soil Composite. Journal of Yangtze River Scientific Research Institute, 2, 112-118.
[13] Shi Haoting, Xie Chunyan, Li Xueer and Wu Dake.(2019) Shear Performance of Soil Slope Protection Under Different Root Distribution Modes. Yellow River, 4, 74-77+82.
[14] Kong Gangqiang, Wen Lei, Liu Hanlong and Wang Chengqing.(2019) Strength Properties of Root Compound Soil and Morphological Observation of Plant Root. Rock and Soil Mechanics, 10, 3717-3723.
[15] Qiang Jiaojiao, Yan Zhehao, Chen Yun, He Binghui, Tang Han and Liu Xiaohong.(2020) Factors affecting the Shear Strength of Root-soil Complexes from Three Types of Grass Hedgerows in a Karst Area. Acta Prataculturae Sinica, 12, 27-37.
[16] Sun Jian, Liu Ziqi, Zhu Dayun Li Yuan, Li Kaiping and Wang Jin.(2019) Evaluation on Soil Qualities of Different Ecological Restoration Models in Rocky Desertification Control Area. Research of soil and water conservation, 5, 222-228.
[17] Zhang Qiaoyan, Tang Lixia, Pan Lu, Huang Tongli and Chen Long.(2020) Mechanical Properties of Shrubs and Applicability of Model WU in Karst Area. Journal of Yangtze River Scientific Research Institute, 12, 53-58.