Quantitative analysis on shear strength of different bio-embankments

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Abstract. Biological measures on terrace embankment have been widely used, in order to repair the farmland damaged by geological disaster. In this paper, four different types of embankments (Exposed, Single Species, Herb, and Shrub-Herb) were built to determine plant growth condition and the difference of soil shear strength in the restoration of damaged farmland. The results showed that herbs covered slope surface as pioneer species and thrived on the embankment, had a better capacity in soil and water conservation in a short time. The shear strength of bio-embankments was significantly higher than that of the exposed embankment. Additionally, as the plants grew, the shear strength of bio-embankments increased gradually. Great disparity was found in the shear strength of different types of bio-embankments, and Shrub-Herb bio-embankment had the highest shear strength and enhanced ability to resist the landslide disaster.

1. Introduction

China is one of the countries greatly suffered from geologic disasters in the world, such as earthquake, landslide, collapse, and debris flow, especially in the southwestern mountainous area. Deformation of ground surface and destruction of farmland caused by natural disasters, ultimately led to the abandonment of cultivated land without effective arrangements. Terrace renovation is not only a major project in the restoration of farmland damaged by disaster [1], but also an important measure to protect cultivated land resources, improve agricultural ecological environment, and ease the contradiction between human and land. Among these, the stability of terrace embankment is particularly significant to the success of farmland reclamation [2]. The technique of using plants to protect slopes from shallow landslides and instability is known to be an effective form of bio-engineering, and it has been used extensively worldwide [3]. Some research showed [4-7] that the terrace embankments constructed by biological measures had an important role in protecting soil and water resources, preventing and mitigating disaster. Therefore, this paper analyzed the difference of plant roots enhancing shear strength of different biological terrace embankments, and quantitatively studied the increasing effect of slope stability by different biological measures. The information gathered from the study could provide theoretical support for restoration technology of damaged farmland, which is a vital
significance not only to the prevention of landslides, but also to the stability enhancement of farmland damaged by disaster.

2. Materials and methods

2.1. Study area
The study area is located in Shuangxin village, Jiangjin district of Chongqing province. In August 2009, a landslide occurred in the area. This traction soil landslide area was 5.81×10^4 m^2. The volume was 69.7×10^4 m^3. Five years after the landslide, the land was in stable state without follow–up deformations. Although the local farmers had taken certain restoration measures in some parts of the study area, the land was still rugged, and land utilization rate was extremely low along with obvious decline of land benefit (Figure 1). Combined with the actual situation of landslide, this study chose the trailing edge of landslide as the test area, which was most seriously damaged with 120 m long and 30 ~ 100 m wide, a total area of about 9000 m^2.

2.2. Construction and planting of biological terrace embankments
The restoration of farmland damaged by landslide disaster was the premise for constructing bio–embankments. In order to reduce the effect of rainfall infiltration on slope stability, the restoration project (chip – fill – flat – clean– drain) of farmland was implemented at the experimental area between 2014 and 2015, forming four terraces. According to the theory of biodiversity and ecology principle, technological improvements were made in the progress of terraced fields construction from sloping land. Herbs and shrubs, such as Lolium perenne L., Medicago sativa L., Cynodon dactylon (L.) Pers, Amorpha fruticosa L., and Vitex negundo L., were chosen to build bio–embankments. At the end of February 2015, among the four terrace embankments with basic consistent test conditions, the first embankment was chosen as a contrast, and then the planting project was carried out on the lateral slope and the ridge of other three embankments by sowing different plant species. Plant species ratio of different types of bio–embankments is shown in Table 1.

2.3. Data processing
Shear failure is the major failure mode of soil slope. Shear strength is a key input in any stability analysis of soil slopes [8], which is often used to measure soil resistance to shear deformation. Therefore, the quantitative study on the effects of the root system on shear strength contributes to further analysis of stability mechanism of bio–embankments.

After bio–embankments were built, the project team conducted field investigation once every two months from 2015 to 2017; we have set sample plots on the upper, middle, and lower part of these four terrace embankments respectively for excavating vertical soil profile, and measuring plant coverage. 0 ~ 30 cm layer of undisturbed soil sample was sealed with plastic film, and then taken back to laboratory for the direct shear test immediately in order to determine soil shear strength indicators.
Table 1. Planting area and species ratio of different bio–embankments.

| Sample area                          | Sowing dosage of plant species (g/m²) | Planting area (m²) |
|--------------------------------------|-------------------------------------|-------------------|
|                                      | Lolium perenne L. | Medicago sativa L. | Cynodon dactylon (L.) Pers | Amorpha fruticosa L. | Vitex negundo L. |                  |
| First embankment (the control group) | 0                        | 0                   | 0                           | 0                   | 0                   | 0                  |
| Secondary bio–embankment             | 0                        | 30                  | 0                           | 0                   | 0                   | 240                |
| Third bio–embankment                 | 15                       | 10                  | 5                           | 0                   | 0                   | 230                |
| Fourth bio–embankment                | 10                       | 6                   | 4                           | 5                   | 5                   | 270                |

3. Results and analysis

3.1. Growth status of plant on biological terrace embankments

Plant coverage is an important quantitative index, which reflects plant community density. Vegetation plays a positive role in water and soil conservation by intercepting rainfall and alleviating runoff. The ability of reducing water loss and soil erosion intensity is closely related to community types, community structure, etc. Therefore, the degree of coverage is very important to the protection of the terrace embankments.

Due to the fact that five species were planted on the fourth terrace embankment, this study took the fourth terrace embankment as an example to reveal the coverage of the vegetation in different periods (Table 2).

Table 2. Vegetation coverage of the fourth bio–embankment.

| Plant species           | Plant coverage (%) | Three months | Half a year | Nine months | A year | A year and a half |
|-------------------------|--------------------|--------------|-------------|-------------|--------|-------------------|
| Lolium perenne L.       |                    | 60           | 50          | 30          | 25     | 10                |
| Medicago sativa L.      |                    | 10           | 20          | 40          | 30     | 20                |
| Cynodon dactylon (L.) Pers |                 | 20           | 30          | 20          | 15     | 10                |
| Amorpha fruticosa L.    |                    | 5            | 10          | 30          | 50     | 60                |
| Vitex negundo L.        |                    | 0            | 0           | 2           | 3      | 5                 |
| Other native species    |                    | 0            | 5           | 10          | 10     | 15                |

Table 2 showed that the coverage of five plant species increased with the growth time before wilting, and then decreased. Three months after bio–embankments were built, Lolium perenne L. covered the slope surface as pioneer species and thrived on the embankment, which had a better capacity in soil and water conservation in a short time. In addition, Medicago sativa L., Cynodon
Dactylon (L.) Pers, and Amorpha fruticosa L. began to sprout, but the coverage was low. Nine months later, Lolium perenne L. gradually reduced on slope of bio–embankment. Other plant species and some local native species began to appear in plant communities, especially Medicago sativa L. with the highest coverage. One year later, the sequence from the highest to the lowest of plant coverage was: Medicago sativa L., Amorpha fruticosa L., Lolium perenne L., Cynodon dactylon (L.) Pers, Vitex negundo L.. Throughout the succession process of vegetation community, shrubs such as Amorpha fruticosa L. had become the dominant species, herbaceous plants tended to reduce gradually, and other native species were growing, resulting in increasing diversity of vegetation community.

Figure 2. The status of bio–embankments after three months.

Figure 3. Panoramic Image of farmland after a year when bio–embankments were built.

3.2. Shear strength of biological terrace embankments

Table 3 shown here, the shear strength of other three bio–embankments was significantly higher than that of the exposed embankment, indicating that the plants on different types of bio–embankments could enhance the shear strength of soil. Plant roots embedded and entangled into pores of soil [9], which seems like adding fine steels in the bio–embankments, is similar to reinforced concrete structure [10], which led to an increase in the shear strength of bio–embankment. Meanwhile, the shear strength of bio–embankments changed dynamically due to different plant growth stages, and the difference of the shear strength was obvious. With time, as the plants grew, the shear strength of bio–embankments increased gradually.

It can be seen from Table 3 that, great disparity was found in the shear strength of different types of bio–embankments. The significance order from high to low of the shear strength of different bio–embankments was fourth bio–embankment, third bio–embankment, and secondary bio–embankment, which indicates that shrub–herb bio–embankment had the highest shear strength and stability, followed by herb bio–embankment, single species bio–embankment. In general, herbs with fibrous root system had a reinforcement effect [11], and shrubs containing more vertical roots downward through the shear sliding surface played a very good anchor role in soil [12].
Table 3. Shear strength of different bio–embankments.

| Sample area                      | Half a year | Eight months | Ten months | A year | Fourteen months | Sixteen months | A year and a half |
|----------------------------------|-------------|--------------|------------|--------|-----------------|----------------|------------------|
| First embankment (the control group) | 21.4        | 22.6         | 21.1       | 23.5   | 23.4            | 23.1           | 23.5             |
| Secondary bio–embankment         | 20.8        | 21.4         | 20.4       | 22.3   | 22.9            | 23.1           | 23.9             |
| Third bio–embankment             | 20.5        | 22.8         | 22.4       | 23.6   | 24.3            | 24.3           | 24.9             |
| Fourth bio–embankment            | 21.9        | 22.1         | 24.9       | 24.7   | 25.8            | 26.5           | 28.6             |

4. Conclusions

The shear strength of bio–embankments in the farmland damaged by landslide disaster was significantly higher than that of the exposed embankment, due to the existence of plant roots system. The growth of plant roots in bio–embankment increased the friction between soil and roots, anchor potential sliding soil of the shallow layer into the depths, thus improving the stability of bio–embankment. Therefore, the enhancement of the stability of bio–embankment is achieved by the interaction between the root system and the soil. The fact that shrub–herb bio–embankment had the highest shear strength and stronger ability to resist the landslide, is confirmed by values of the direct shear test, which provides a theoretical basis for the restoration of farmland damaged by landslide disaster and construction mode of bio–embankment.

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References

[1] Shi G H and Sun H F 2006 Exploring of Terrace Edge/Ridge in Gansu Province Research of Soil and Water Conservation 13 74
[2] Wang X L, Cai Q G, Wang Z K, and Sun G L 2000 The consolidating function and economic benefit analysis of the terrace hedgerows in the hilly loess region of northwest Hebei Province Journal of Natural Resources 15 74
[3] Stokes A, Salin F and Kokutse A D 2005 Mechanical resistance of different tree species to rockfall in the French Alps. Plant Soil 278 107
[4] Zhang Y Q, Zhu Q K, Qi S, Zhang Y and Wang D M 2005 Acta Ecologica Sinica 25 500
[5] Abe K and Iwamoto M 1988 Preliminary experiment on shear in soil layers with a large direct–shear apparatus Japanese Forestry Soc. 68 61
[6] Nilaweera N S 1994 Effects of tree roots on slope stability: the case of KhaoLuang Mountain area, Thailand Bang–kok: Asian Institute of Technology
[7] Zhou Y, Li H W and Xu Q 2000 Role of Vertical Roots of Young Yunnan Pine on Soil Reinforcement Journal of Soil and Water Conservation 14 100
[8] Hisham T E, Khaleed H R and Dharma W 2016 Drained residual shear strength at effective normal stresses relevant to soil slope stability analyses Engineering Geology 204 94
[9] Thorne C R 1990 Effects of vegetation on riverbank erosion and stability Thornes J.B. Vegetation and Erosion: Processes and Environments (New York: John Wiley and Sons) pp
125–144

[10] Li Q, Zhou B Z, An Y F and Xu S H 2014 Root system distribution and biomechanical characteristics of Bambusa oldhami Chinese Journal of Applied Ecology 25 1319

[11] Zhang Y Q and Qi S 2002 Study on terrace bio–embankment in China: present situation and trend World Forestry Research 15 49

[12] Zhang Y Q, Qi S and Wen M X 2003 Primary study on root system foraging space and rooting pattern of plants on the terrace embankments Science of Soil and Water Conservation 1 31